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UPPER JURASSIC AND LOWER CRETACEOUS STRATIGRAPHY OF SOUTHERN ALBERTA AND NORTH-CENTRAL MONTANA

by

© BRAD JAMES RICHARD HAYES

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF DOCTOR OF PHILOSOPHY

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "Upper Jurassic and Lower Cretaceous Stratigraphy of Southern Alberta and North-Central Montana" submitted by Brad James Richard Hayes in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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ABSTRACT

A comprehensive regional study of Upper Jurassic and Lower Cretaceous strata in the pivotal area of southeastern Alberta and north-central Montana is carried out in this thesis and integrated with published studies from surrounding areas to formalize and correlate lithostratigraphic units, interpret paleogeography, and reconstruct the geological history of the western interior during this time interval.

Marine strata of the Ellis Group make up the Middle and Upper Jurassic section, including predominantly calcareous shales of the Rierdon Formation overlain by the basal dark shale and upper "ribbon sand" members of the Swift Formation. Lower Cretaceous continental strata are assigned to the Blairmore Group because of their similarity to type Blairmore strata of the Alberta Foothills. Within the Blairmore, the basal Cut Bank Formation is defined and correlated with the Cadomin Formation of the Foothills, while the Gladstone and Beaver Mines Formations are extended from the Foothills.

Primarily marine Jurassic strata were deposited over the western interior during three major transgressive events occurring in the Middle and Late Jurassic. Larger areas were inundated by each successive transgression, resulting in deposition of very widespread homogeneous lithological

units during the Late Jurassic. The sea retreated from the cratonic basin after the Oxfordian until early Albian time. Limited continental aggradation took place to the south of the thesis area during the latest Jurassic and earliest Cretaceous, while the land in central and northern areas was deeply dissected. Collision of allochthonous terranes with the western edge of the North American craton resulted beginning in the uplift of western source areas in the Late Jurassic, but significant amounts of coarse clastic detritus were not deposited on the craton until the late Neocomian. Terrestrial sediments, characterized by siliceous lithologies, accumulated over the entire western interior during the Aptian. Base level rose in the earliest Albian as the Boreal sea advanced, triggering extensive deposition of lacustrine and marginal marine facies. At about the same time, renewed uplift and exposure of igneous source rocks to the west caused a sharp influx of feldspathic sediments into the cratonic and foreland basins.

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Shell Canada Resources Ltd. employed the author while gathering data in 1979 and provided technical support throughout the entire term of study. Mr. A.P. Audretsch and Miss K. Leskiw performed paleontological analyses and interpretations. Thin sections were cut under the direction of Mr. I. Van der Veer at the Shell research laboratory, and the cross-sections were drafted with the guidance of Mr. A. Rupp. Shell also provided funds for field work in Montana.

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I. INTRODUCTION

A. Background and Goals

Stratigraphic correlation and the interpretation of geologic history within the great interior basins of the world have always been difficult because the conventional methods of field geology cannot be applied to strata buried deep in the subsurface. Little outcrop is available for examination because of the small amount of structural displacement of strata. In the northern Great Plains of North America, moreover, outcrops are hidden by a thick mantle of unconsolidated sediments deposited by Pleistocene continental glaciers.

Fortunately for the practitioners of stratigraphy in western North America, the hunt for petroleum during the past sixty years has provided abundant subsurface geological data. Although seismic data, geophysical logs, drilling samples and the occasional core do not provide geological data comparable in quality to that derived from surface mapping, it is possible to collect sufficient information to reconstruct the history of the sedimentary rocks far beneath our feet.

In the Plains of southern Alberta and northern Montana, petroleum exploration has been pursued actively since the early 1920's. Commercial discoveries of oil and gas have been made in numerous stratigraphic systems, but most successful plays have been completed in rocks of

Mississippian, Jurassic, and Cretaceous age. As most of these plays are relatively small and isolated, however, the stratigraphic control points tend to occur in small dense clusters. Consequently, correlations between fields have been somewhat haphazard and often conflicting. Although some regional studies have been published, these all suffer from poor control, either because they were done more than 30 years ago when a good distribution of wells did not exist, or because they encompass such large areas that it was not possible to incorporate a high density of control points.

A particularly difficult problem of stratigraphic correlation in southern Alberta and northern Montana has been the distinction and delineation of the Upper Jurassic and Lower Cretaceous Series. Severe erosion and channelling occurred between the Mississippian and Middle Jurassic and again between the mid-Late Jurassic and mid-Early Cretaceous. In addition, the Lower Cretaceous rocks are of nonmarine origin; they are, therefore, highly variable in lithology and difficult to correlate over significant distances.

This problem is not restricted to western North America. Arkell (1933, 1956) documented the Jurassic System of Great Britain and other parts of the world, noting in the Upper Jurassic of many areas the lack of easily-correlated marine fauna such as ammonites. Allen (1955) emphasized the difficulty of using facies-controlled fauna to correlate nonmarine strata outside the English Basin with the classical Neocomian (basal Cretaceous) English Weald section. More recent works, such as the papers in the Boreal Lower Cretaceous volume edited by Casey and Rawson (1972) and the discussions of Arkell (1956) and Hallam (1975), show that faunal provincialism complicates world-wide correlation of the Upper Jurassic and Lower Cretaceous Series. Palynological and micropaleontological knowledge is now sufficiently advanced, however, to be of use in correlation of nonmarine sedimentary rocks near the Jurassic - Cretaceous boundary, but the systematic application of this knowledge is only in its early stages.

The major objective of this thesis to describe and correlate Upper Jurassic and Lower Cretaceous strata in the Plains of southern Alberta and north-central Montana, and to extend these correlations and interpretations to include contemporaneous strata over much of the western interior of North America. The available well control is now sufficient to map these strata accurately and to produce a detailed reconstruction of geologic events leading to their deposition.

B. Objectives

In order to attain the overall objective set out above, the author defined a number of more specific objectives.

1. Define lithostratigraphic units and pick their boundaries in each well. This is done by considering

previously-defined formations, and using core data, sample data, and geophysical logs.

2. Construct a grid of intersecting west-east and north-south cross-sections in conjunction with objective (1). This grid aids in correlating formation boundaries and in illustrating the behaviour of the lithostratigraphic units over the area.
3. Map the thickness and structural configuration of the units.
4. Determine depositional environments and facies relationships on the basis of patterns of lithologic variations and paleontological paleoenvironmental data.
5. Make age determinations and clarify facies relationships using paleontological data.
6. Interpret the major depositional and erosional controls on the distribution of each formation by combining the results of objectives (3), (4), and (5).
7. Integrate the resultant stratigraphic scheme with those from surrounding areas to make regional correlations.
8. Reconstruct the geological history by compiling and interpreting the data from objective (7).
9. Briefly investigate the economic significance of this work by applying the results to hydrocarbon exploration strategies.

C. Area of Study

The area examined occupies the southeastern corner of the Province of Alberta, and a contiguous area to the south in the State of Montana (Fig. 1). It is bounded on the east by the Fourth Meridian of the Dominion Land Survey (Long., 110° W) in Canada, which is the eastern border of Alberta. This boundary continues directly south into Montana, where it runs within Range 13 East of the Principal Meridian of that state (all range designations in Montana are referred to the Principal Meridian). The western boundary is the western edge of Range 20 West of the Fourth Meridian in Alberta (112° 40'W), which corresponds to Range 8 West in Montana. The northern boundary is the northern edge of Township 15 in Alberta (Lat. 50° 19'N), and the southern boundary runs along the southern edge of Township 30 North of the Montana Base Line in Montana (48° 18'N - all township designations in Montana are referred to the Montana Base Line). The total area encompassed is approximately 460 townships, which is 16,560 square miles (44 650 square kilometres).

A number of factors governed the choice of the boundaries detailed above. As discussed in the next section, abundant data are available from the numerous oil and gas fields. Because the area straddles the international border, direct comparison of American and Canadian stratigraphic nomenclature can be made. Similarly, the different stratigraphic schemes east and west of the

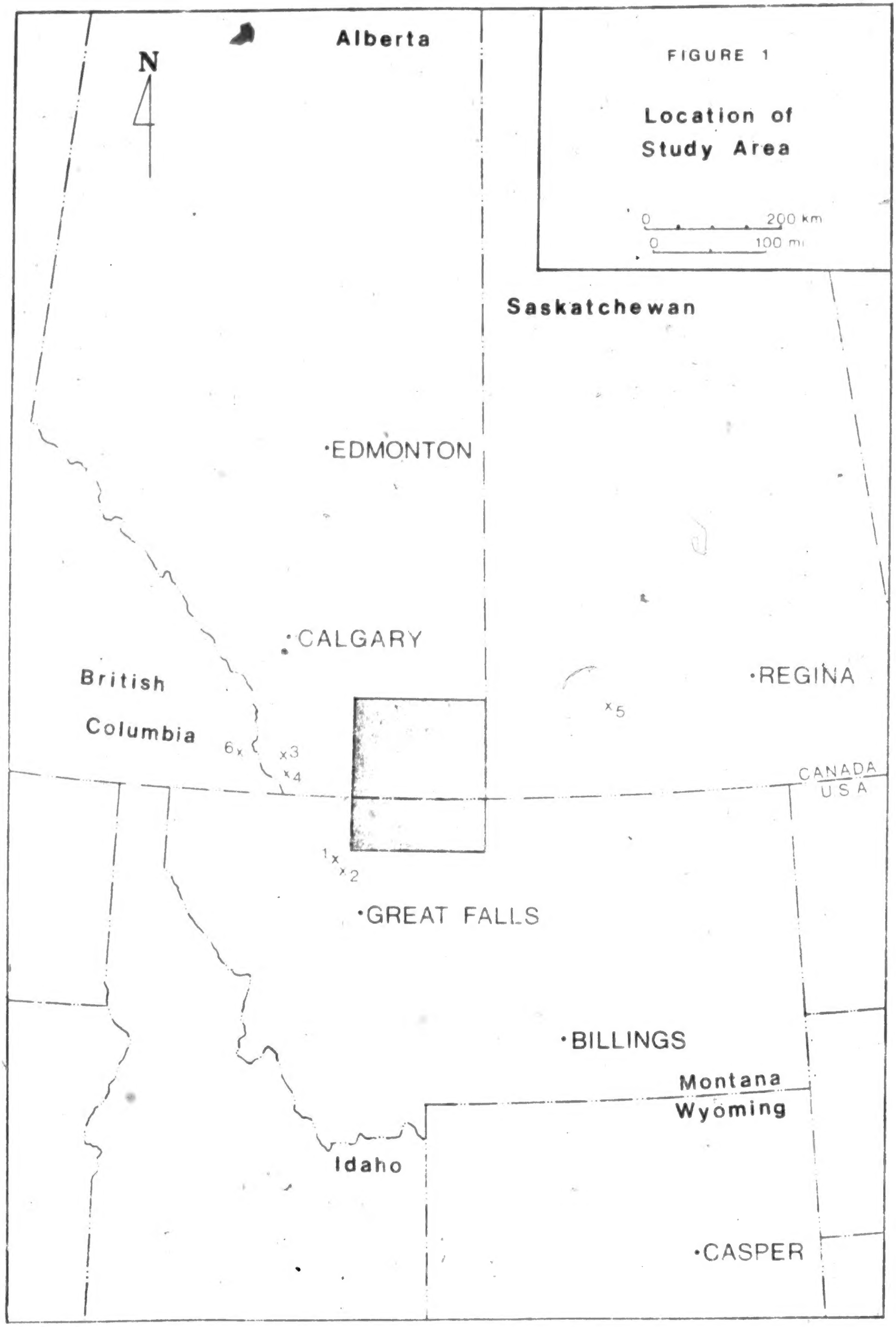

N
Alberta
0
200 km
0
100 mi
Saskatchewan
EDMONTON
CALGARY
REGINA
British Columbia
6
3
4
5
CANADA
USA
1
2
GREAT FALLS
BILLINGS
Montana
Wyoming
Idaho
CASPER

FIGURE 1

Location of Study Area

Cities shown here are abbreviated in following figures. Locations mentioned in text: 1. Swift Reservoir; 2. Rierdon Gulch; 3. Blairmore; 4. Gladstone Creek; 5. Swift Current; 6. Fernie

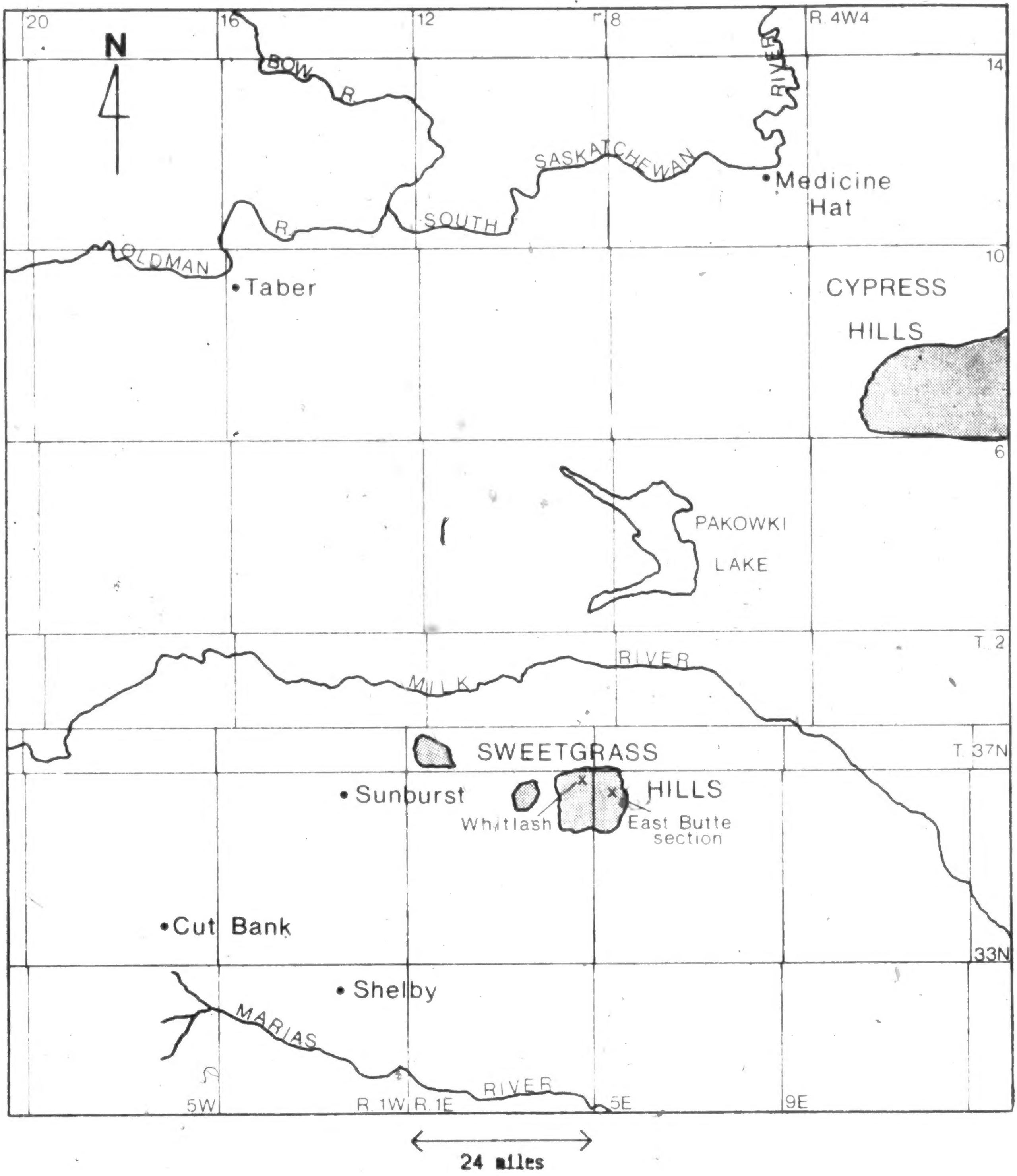

20
16
12
8
R. 4W4
14
N
BOW R.
SOUTH SASKATCHEWAN RIVER
R. SOUTH
OLDMAN
Medicine Hat
10
Taber
CYPRESS HILLS
6
PAKOWKI LAKE
T. 2
MILK RIVER
T. 37N
SWEETGRASS HILLS
Sunburst
Whitlash
East Butte section
Cut Bank
33N
Shelby
MARIAS RIVER
5W
R. 1W
R. 1E
5E
9E
24 miles

Fig. 2. Physiography, drainage, and major towns, southeastern Alberta and north-central Montana.

Sweetgrass Arch can be related. Finally, the pinchout of Jurassic strata in the northern part of the study area is useful in the interpretation of the nature of pre-Cretaceous erosion.

This part of the Great Plains is a relatively featureless prairie, interrupted by only a few bedrock features such as the Sweetgrass Hills and the Cypress Hills (Fig. 2). Pleistocene glaciations were the dominant force in the shaping of the present-day surface; glacial spillways and other channels, many presently occupied by streams, provide the only other significant relief. Modern-day drainage in the southern half of the area is through the Milk River system, which empties into the Missouri-Mississippi system and eventually to the Gulf of Mexico. To the north, the Oldman River merges with the Bow to form the South Saskatchewan, which drains into Hudson Bay.

D. Data Collection and Utilization

Several varieties of subsurface data were employed in order to gain maximum stratigraphic control. Table 1 and Fig. 3 summarize the amount, type, and distribution of data points.

Overall, 535 control points were used, a control density of 1.16 points per township, or about one point every 31 square miles. This density is far greater than that used in previous published studies, and is sufficient

	ALBERTA	MONTANA	TOTALS
Core	150	20	170
Samples	79	0	79
Logs only	132	154	286
Totals	361	174	535
Area (Townships)	300	160	460
Control Points / Township	1.20	1.09	1.16

Table 1. Well control, by type and area.

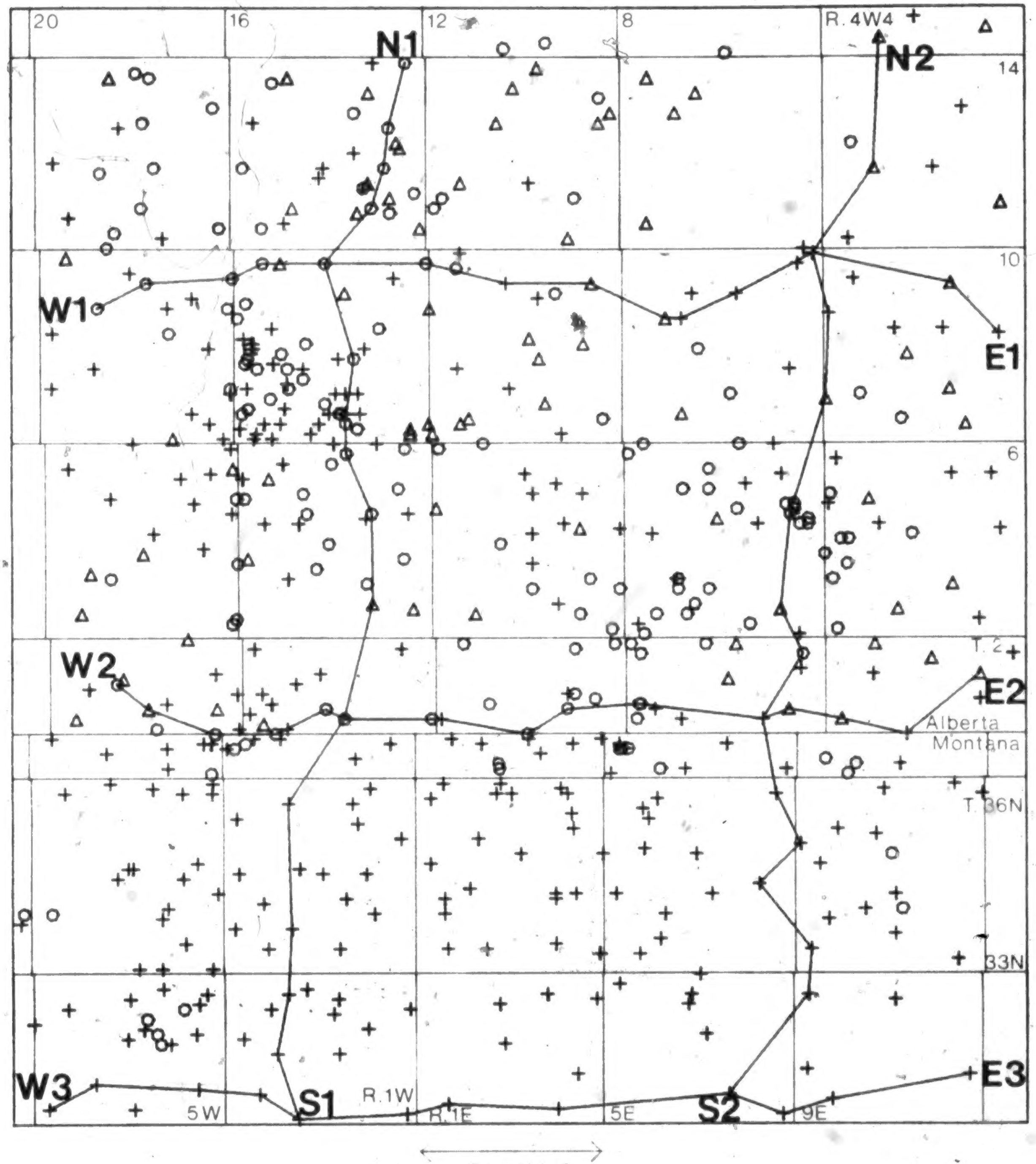

20
16
12
8
R. 4W4
N1
N2
14
10
6
T. 2
W1
E1
W2
E2
Alberta
Montana
T. 36N
33N
W3
S1
S2
E3
R. 1W
R. 1E
5W
5E
9E
24 miles

Fig. 3. Location map, well control, and cross-sections. Circles indicate wells with cores, triangles wells with sample control, and crosses wells with geophysical logs only.

to map stratigraphy accurately while maintaining a manageable quantity of data. Care was taken to use an even distribution of control points by selecting one well with high-quality geophysical logs, sufficiently deep penetration, and drill cores (where possible) from each township. In some areas, however, most notably the extreme northeast and southeast, there are simply no wells which penetrate Lower Cretaceous or Upper Jurassic strata.

The quality of data from Alberta is much superior to that from Montana (Table 1), despite a longer history of petroleum exploration in Montana. Long-standing provincial legislation in Alberta ensures the submission of all well data, including drill cores and drilling samples, to the Energy Resources Conservation Board, which then allows public access to these data. In Montana, similar legislation now exists, but it is not so well enforced; consequently, many data have been lost or are otherwise not available.

Nearly all the available drill cores taken from the strata of interest were examined; only some closely-spaced cores from Alberta oil fields were not included. Combined with geophysical well logs, cores provide the highest quality data, as lithologies and sedimentary structures can be determined accurately. Where core was not available, drilling samples, published logs of drilling samples (by Canadian Stratigraphic Service Ltd. and American Stratigraphic Company), and/or geophysical logs were used.

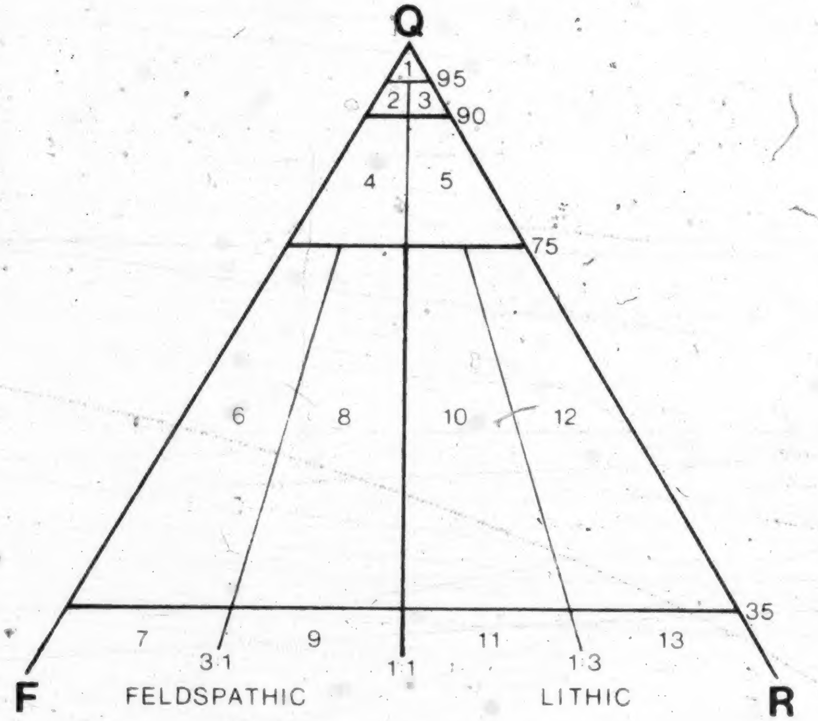
Examination of drilling samples and sample logs, however, was found to be of little value because of their poor quality, which can be attributed partly to abundant caved material from the overlying Colorado Group shales. Rapid drilling through the Cretaceous and Jurassic, as the drilling objective is often Mississippian strata where the complete interval is penetrated, also detracted from sample quality. Fortunately, complete suites of geophysical logs were available for both Alberta and Montana. Electrical logs provided most of the data; these were supplemented by gamma, sonic and density logs where available.

In addition to the subsurface well data described above, one outcrop section was examined. Most completely described by Sanderson (1931) and Russell and Landes (1940), the section is exposed on the banks of Sage Creek, which flows off East Butte in the Sweetgrass Hills (Section 8, Township 36N, Range 5E) (Fig. 2). Mississippian and younger strata are brought to the surface here on the flanks of the Tertiary intrusive masses making up the Sweetgrass Hills (Chapter 3). Several other sections outside the study area were of value in the correlation of subsurface stratigraphy with previously-described stratigraphic units. These include several outcrops in the Great Falls area, discussed in detail by Walker (1974), the section at Swift Reservoir, Montana (Township 28N, Range 10W) (Fig. 1), described by Cobban (1945), and a number of sections in the eastern Big Horn Basin of northern Wyoming (Fig. 5a).

From samples collected from cores and outcrop sections, approximately 300 thin sections were made. Each was examined and described petrographically according to the classification scheme of Chen (1968) (Fig. 4). This scheme was chosen because it best distinguishes sandstones composed primarily of quartz and chert, as were most of those examined in this study.

Approximately 300 samples were taken for the purpose of palynological and micropaleontological analysis. Other workers processed and examined the samples and interpreted the floral and faunal assemblages in terms of environment of deposition and age (see Appendix A). Their interpretations were sometimes at variance, largely because of poor preservation or ambiguous nature of the assemblages. The results were useful, however, as a tool of stratigraphic correlation and in interpreting environmental conditions.

Published descriptions of individual oil and gas fields, along with regional compilations incorporating regional cross-sections and/or interpretative well logs were instrumental in providing a base upon which to construct a geological synthesis from the collected data. It must be emphasized, however, that almost all published studies suffer greatly from a lack of consideration of sufficient core and outcrop data, as lithological variations are rather subtle and continuous marker horizons are scarce. Geophysical logs alone therefore do not provide sufficient information for unambiguous correlation across large


Q
1
95
2
3
90
4
5
75
6
8
10
12
35
7
9
11
13
3:1
1:1
1:3
F
FELDSPATHIC
LITHIC
R

1. Pure quartzarenite
2. Feldspathic quartzarenite
3. Lithic quartzarenite
4. Subarkose
5. Sublitharenite
6. Arkose
7. Extra-arkose
8. Lithicarkose
9. Extralithicarkose
10. Fellitharenite
11. Extrafellitharenite
12. Litharenite
13. Extralitharenite

Fig. 4. Sandstone classification and nomenclature scheme (after Chen, 1968). Q = quartz; F = feldspar; R = rock fragments.

distances.

Contour maps were prepared by the SURFACE II Graphics System, available on the Amdahl computer system at the University of Alberta. These maps are not as interpretive as they would be if drawn by hand, because the mapping program tends to average and smooth out small-scale features such as small stream channels. They are adequate, however, for illustrating regional stratigraphy.

All measurements are reported in Imperial units, as the well locations are surveyed in miles and feet, and all but the most recent cores from Alberta are measured in feet.

II. PREVIOUS WORK

A. Stratigraphy

Much literature has been published on various aspects of the Upper Jurassic and Lower Cretaceous of this area, and numerous private industry reports also exist. Most of this work, however, is limited to individual fields or small areas; only a few papers make significant contributions to our knowledge of the general stratigraphy. These important steps toward the development of the present stratigraphic framework are summarized here (Table 2). The history and designation of individual lithostratigraphic units will be discussed in Chapter 4.

G.M. Dawson (1886) published the first comprehensive investigation of Jurassic and Cretaceous rocks in the western interior. He established some Mesozoic nomenclature and described strata cropping out in the southern Canadian Rocky Mountains and Foothills. Sir J.W. Dawson (1885) and G.M. Dawson (1885) discussed the Mesozoic fossil floras of the area, and proposed the name "Kootanie" for a Lower Cretaceous rock unit underlying the Dakota Formation, which had been correlated northward from the United States. Leach (1914) first used the name "Blairmore" to designate the section of Lower Cretaceous strata previously assigned to the Dakota. He clearly distinguished it from the underlying Kootenay Formation (revised Canadian spelling of the Dawsons' Kootanie), using lithological criteria.

J.W. Dawson G.M. Dawson (1885) ALBERTA FOOTHILLS	Rose (1916) ALBERTA FOOTHILLS	Fisher (1909) CENTRAL MONTANA	Cobban (1945) NORTHERN MONTANA		Glaister (1959) SOUTHERN ALBERTA		THIS STUDY	
Dakota	Blairmore	Kootenai	Kootenai		MANNVILLE	Upper	BLAIRMORE	Beaver Mines
						Lower		Gladstone
	Blairmore cg.							Cut Bank
Kootanie	Kootenay	Morrison	Morrison					
?	?	Ellis Formation	ELLIS	Swift	ELLIS	Swift	ELLIS	Swift
				Rierdon		Rierdon		Rierdon
				Sawtooth		Sawtooth		Sawtooth / Shaunavon

Table 2. Abbreviated historical development of Upper Jurassic and Lower Cretaceous lithostratigraphic nomenclature in southern Alberta and northern Montana.

Rose (1916) followed Leach's correlations, but moved the cherty conglomerate now called the Cadomin Formation from the top of the Kootenay to the base of the Blairmore, calling it the 'Blairmore conglomerate'. The Blairmore - Kootenay nomenclature was generally accepted by other workers in Canada after 1915. MacKay (1929) named and described the Cadomin Formation from exposures along the Rocky Mountain Foothills west of Edmonton. Although he did not designate a type section, he described the formation in detail and noted that it could be mapped for at least 70 km. along strike. MacKay also tentatively correlated the Cadomin with the Blairmore conglomerate of the southern Rockies, although neither unit had been traced along the mountain front between the Saskatchewan and Bow Rivers.

Weed (1892) first noted the presence of Lower Cretaceous rocks in the northern Plains. He extended the use of the name "Kootanie" to strata cropping out near Great Falls, Montana, based on a comparison of the flora with that described by the Dawsons, and on the general similarity of the coal and sandstone units present in each area. In 1899, Weed also recognized strata of probable Jurassic age in a nearby area.

Fisher (1907, 1909) recognized three major rock units of interest in the Great Falls coal field. He extended the Middle to Upper Jurassic Ellis Formation, consisting mostly of marine shales and limestones, from southern Montana to the lowest unit. About 100 feet of strata were assigned to the Morrison Formation of probable Jurassic age, based on lithological similarities with the well-known Morrison of Colorado. Above this, he assigned a 475-foot section of continental sedimentary rocks to the "Kootenai" Formation of Early Cretaceous age, remarking on the presence of abundant coal in the lower member. It was obviously his intention to correlate the Kootenai both lithologically and on the basis of floral content with the Kootanie of the Dawsons. In 1908, Fisher extended his units over large areas to the south. Stebinger (1916) recognized Fisher's Kootenai in the north-central part of Montana, but he discussed the Jurassic only briefly, not mentioning the Ellis or Morrison Formations. In 1918, Stebinger also described the Kootenai and Ellis in northwestern Montana, but could not recognize the Morrison in this area.

McLearn and Hume (1927) criticized the correlation of the Kootenai of Fisher and his followers, noting that it corresponded to the Kootenay plus at least a part of the Blairmore Formation. Cobban (1945) formally extended the Morrison to include the basal coal-bearing member of Fisher's Kootenai, and proposed a substantial unconformity containing the Jurassic - Cretaceous boundary at the new base of the Kootenai, therefore correlating the Kootenai with the Mannville and Blairmore Formations of Alberta. Walker (1974) reaffirmed these correlations, and discussed in detail the deposition of the Morrison and Kootenai in the Great Falls area. Because of the unusual history and changing definition of the Kootenai, no formal type section was ever established.

In the southern Plains of Alberta, Dowling (1917), Dowling et al. (1919), and McLearn (1932, 1945) made brief mention of the Lower Cretaceous, referring to the "varicoloured beds". Russell and Landes (1940) published the first comprehensive Canadian study, in which they picked the top of the Lower Cretaceous at the top of a sequence of red and green shales which they correlated with the Blairmore Formation. McLearn (1945) and Russell and Landes (1940) realized that the coal-bearing Kootenay Formation, of Late Jurassic and possibly earliest Cretaceous age, does not extend under the Plains. Glaister (1959) defined the Lower Cretaceous Mannville Group in southern Alberta, correlating it with the Mannville Group of central Alberta, the lower two-thirds of the Blairmore Group of the Foothills, and the Kootenai formation of Montana. He also informally defined the upper and lower Mannville formations and discussed a number of informal members in the present study area.

In the southern Canadian Foothills, Glaister divided the Blairmore Group into upper and lower formations. Mellon and Wall (1963), using lithological and paleontological criteria, designated three informal units of formation status: the lower, middle, and upper Blairmore. Norris (1964) proposed a principal reference section (hypostratotype) of the Blairmore Group, and divided it into five units: the Cadomin Formation, the lower Blairmore, calcareous member, middle Blairmore, and upper Blairmore. Finally, Mellon (1967) gave the Blairmore Group formal lithostratigraphic status, naming and designating type sections for three constituent formations: Gladstone (lower Blairmore of Mellon and Wall (1963)), Beaver Mines (middle), and Mill Creek (upper). McLean (1977) objected to Mellon's designation of the Cadomin as the basal member of the Gladstone; instead, he proposed that the Cadomin retain formation status, and that the Gladstone be redefined to comprise the strata between the Cadomin and Beaver Mines Formations.

Eldridge (1896) first described and named the Upper Jurassic Morrison Formation from outcrops in the vicinity of Morrison, Colorado. The formal type section, established by Waldschmidt and Leroy (1944), is composed of continental sediments much like those of the Kootenai and Mannville. Numerous papers concerning the Morrison have since been published because of its content of economic deposits of uranium and coal. Walker (1974) summarized the nature and distribution of the Morrison in the western United States.

Marine Middle and Upper Jurassic strata of northern Montana were defined and discussed by Cobban (1945), who elevated the Ellis Formation to group status and subdivided it into the Sawtooth, Rierdon, and Swift Formations. Weir (1949) extended Cobban's nomenclature into southern Alberta, and outlined the northern erosional edge of the

Jurassic System. Few other papers have dealt with the Ellis Group in detail, but Frebold (1953), Carlson (1968), and Peterson (1966) provide some of the major contributions toward the correlation of the Ellis with strata of surrounding areas.

Other major stratigraphic papers are primarily syntheses of earlier work, or are concerned with adjoining areas. These works include: Imlay (1952a, c), Cobban and Reeside (1952), Peterson (1957a, 1972), Rudkin (1964), Springer _et al_. (1964), McGookey _et al_. (1972), Stelck _et al_. (1972), and Herbaly (1974).

B. Paleontology

Supporting the major stratigraphic works summarized above are numerous important contributions to Jurassic - Cretaceous paleontology of the western interior. Details regarding age dating of individual stratigraphic units will be discussed later.

Fossil Floras

Sir J.W. Dawson (1885) presented the earliest relevant paleontological work on the Mesozoic floras of the southern Canadian Rockies. As previously discussed, he described these floras briefly and assigned an earliest Cretaceous (sub-Dakota) age to the Kootanie unit. Little detailed paleontological work was published in the following 60 years, although Weed (1892), Fisher (1908), and Rose (1916) stated that fossil plants were used to support their stratigraphic correlations.

Brown (1946) discussed floras near the Jurassic - Cretaceous boundary in Montana and Alberta, assigning a Late Jurassic age to the Morrison and an Early Cretaceous age to the Kootenai and lower Blairmore. He thus provided additional evidence for Cobban's proposal of a marked Jurassic - Cretaceous unconformity in the northern Plains. Bell (1956) published the most complete and detailed description of floras of Lower Cretaceous strata in the Canadian Rockies and Foothills. In this work, he emphasized the difficulty of accurate dating because of generally poor and long-ranging floras; however, he was able to assign a Portlandian to Barremian age to the Kootenay Formation, and an Aptian - Albian range to the Blairmore. In the Plains of east-central Alberta, Singh (1964) described the microfloras of the Mannville G oup. By tracing the evolutionary succession and by careful comparison with European microfloras, he concluded that Lower Mannville deposition spanned late Barremian (or later) to early Albian time, and that the Upper Mannville was laid down during early to middle Albian time.

Several significant palynological contributions were made by S.A.J. Pocock (1962, 1964, 1970, 1972, 1976). Pocock (1962) reviewed previous work regarding dating of strata near the Jurassic - Cretaceous boundary in the western Canadian Plains, and graphically analyzed microfloral occurrences in several Upper Jurassic and Lower

Cretaceous stratigraphic units. Pocock (1970, 1972) exhaustively studied the palynology of Jurassic sediments across western Canada, and used his results to make detailed paleogeographical interpretations for a number of intervals during the Jurassic Period. Although these studies are a valuable contribution, the present author has noted some inconsistencies in the correlation of strata from which samples were taken, which will be discussed in Chapter V. In 1976, Pocock set forth a preliminary dinoflagellate zonation of the uppermost Jurassic and part of the Lower Cretaceous in the Canadian Arctic, with suggestions for correlations with the Western Canada Basin. Significantly, he assigned post-Neocomian ages to Lower Cretaceous strata of southern Alberta, in agreement with age determinations made by Singh (1964). Previously, Pocock (1962, 1970) had postulated a Neocomian age for these sediments.

Fossil Faunas

Published work on faunas did not appear until long after the first investigations of fossil floras. This can be attributed in part to the fact that fossiliferous marine rocks are much less abundant and generally not as well exposed in this area, and were not studied in detail until the mid-20th century.

Loeblich and Tappan (1950a, b) described numerous species of foraminifera from the type section of the Sundance Formation of South Dakota, and compared this fauna with that from outcrops of the Rierdon Formation in Montana, to the southeast of the present study area. In a like manner, Swain and Peterson (1951, 1952) catalogued the ostracod fauna of the type Redwater Shale Member of the Sundance Formation and compared it with other Oxfordian microfaunas, including that of the Swift Formation in central Montana. Peterson (1954) continued this work by examining and comparing Lower Sundance and Rierdon ostracods. He found that a major microfaunal break exists between the Swift and Rierdon, and that western interior microfaunas of the Upper Jurassic are completely dissimilar to Gulf Coast microfaunas, thus suggesting a physical barrier between the two areas at that time. Loranger (1955) discussed the paleogeography of Jurassic microfossil zones in the Western Canada Basin, and provided a reference list of supporting paleontological investigations of more limited scope.

The megafaunas of the marine Middle to Upper Jurassic Ellis Group of Montana were described by Cobban et al. (1945) and Cobban (1945). Imlay (1947) surveyed the faunas of this age over the entire western interior of the United States, correlating the observed ammonite zones with the standard European zonation. In 1957, he used the fossil data to aid in the paleoecological reconstruction of Jurassic seas in the western interior.

Some papers published on the Jurassic paleontology of surrounding areas are of interest to this investigation. Frebold (1957) and Frebold et al. (1959) are the most comprehensive papers on the Jurassic megafaunas of western Canada. Brooke and Braun (1972), building on the earlier work of Wall (1960), described in detail the microfaunas of the Jurassic System of Saskatchewan and north-central Montana east of the present study area. Abundant paleontological literature concerning the Upper Jurassic Morrison Formation exists, but it is primarily concerned with megafauna, most notably dinosaur remains. Such faunas are of little significance in a subsurface study such as this, as it is extremely unlikely that identifiable fragments could be recovered.

The Lower Cretaceous of the study area is largely barren because of its nonmarine origins. Only the "Ostracod zone" or "Calcareous" member has yielded significant microfaunal assemblages. Loranger (1951) described these faunas and Glaister (1959) correlated and discussed the significance of the fossil zone across Alberta and northern Montana. In central Alberta, Nauss (1947) described the foraminifera and ostracods of Cretaceous strata slightly younger than the "Calcareous" member. Caldwell _et_. _al_ (1978), in setting up a foraminiferal zonal scheme for the Cretaceous of the interior Plains, however, were unable to extend their Lower Cretaceous zones into the Mannville group of the southern Plains.

III. STRUCTURAL SETTING

The position of major structural entities and the history of movement of these features are important governing factors in the deposition of sediments. In southeastern Alberta and north-central Montana, the dominant structure is the Sweetgrass Arch, which has lain at the western edge of the stable North American craton throughout much of Phanerozoic time. To the east, strata descend into the Williston Basin; to the west, into the Alberta Syncline or its southern equivalents (Fig. 5a). The Sweetgrass Arch and Williston Basin, being large-scale cratonic structures, were fairly stable during the Phanerozoic; consequently, little structural deformation of the sedimentary rocks deposited over them has occurred. Minor folding and normal faulting are found in the Alberta Syncline, but no major structural deformation is encountered east of the Rocky Mountain fold and thrust belt. The fold and thrust belt lies considerably to the west of the Alberta portion of the study area, but it is very close to the southwestern corner of the area in Montana.

These three major structural features - the Sweetgrass Arch, Williston Basin, and Alberta Syncline - and some of the more important minor structures are discussed in more detail below.

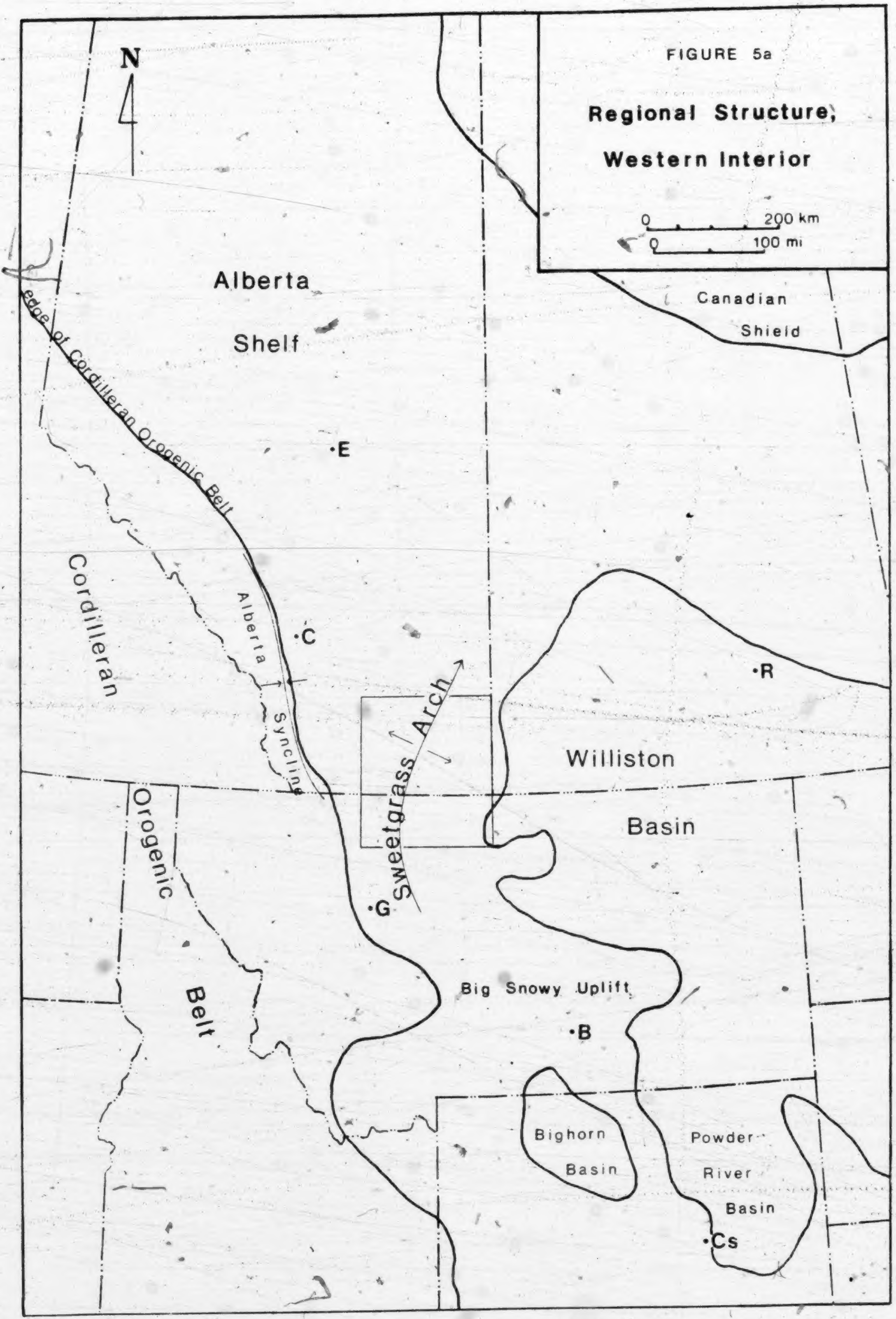


FIGURE 5a
Regional Structure, Western Interior
0 200 km
0 100 mi
N
Alberta Shelf
edge of Cordilleran Orogenic Belt
Canadian Shield
E
C
Alberta Syncline
Cordilleran Orogenic Belt
Sweetgrass Arch
R
Williston Basin
G
Big Snowy Uplift
B
Bighorn Basin
Powder River Basin
Cs

Source: after Christopher (1980)

A. Sweetgrass Arch

The first detailed investigation of the Sweetgrass Arch was published by Romine (1929), who recognized the en echelon northwest-trending Kevin - Sunburst Dome and South Arch as components of the Sweetgrass Arch (Fig. 5b). Michener (1934) considered the arch to be a single large fold, the axis of which trended northwest from central Montana into southern Alberta, there shifting to the northeast and losing its identity north of Medicine Hat. Tovell (1958) concluded that the arch is indeed a composite feature (Fig. 5b). He traced generally northwesterly-plunging fold axes to a culmination in northern Montana, which is the Kevin - Sunburst Dome. To the south, paralleling the axis of the Kevin - Sunburst Dome and the edge of the Cordilleran Orogen is the South Arch. Tovell considered the northeasterly-trending portion of the Sweetgrass Arch to be a separate northeasterly-plunging anticline, which he named the Bow Island Arch. Instead of simply dying out, as suggested by Tovell, the Bow Island Arch was shown by Herbaly (1974) to pass through the Suffield Saddle; to the north, the trend is continued by the southwesterly - plunging North Battleford Arch (Fig. 5b).

The Sweetgrass Arch is thus composed of three major substructures. Both Tovell (1958) and Herbaly (1974) emphasized that the designation of a single arch is a matter of convenience only, and that a single origin cannot be ascribed to the entire structure. The position of the

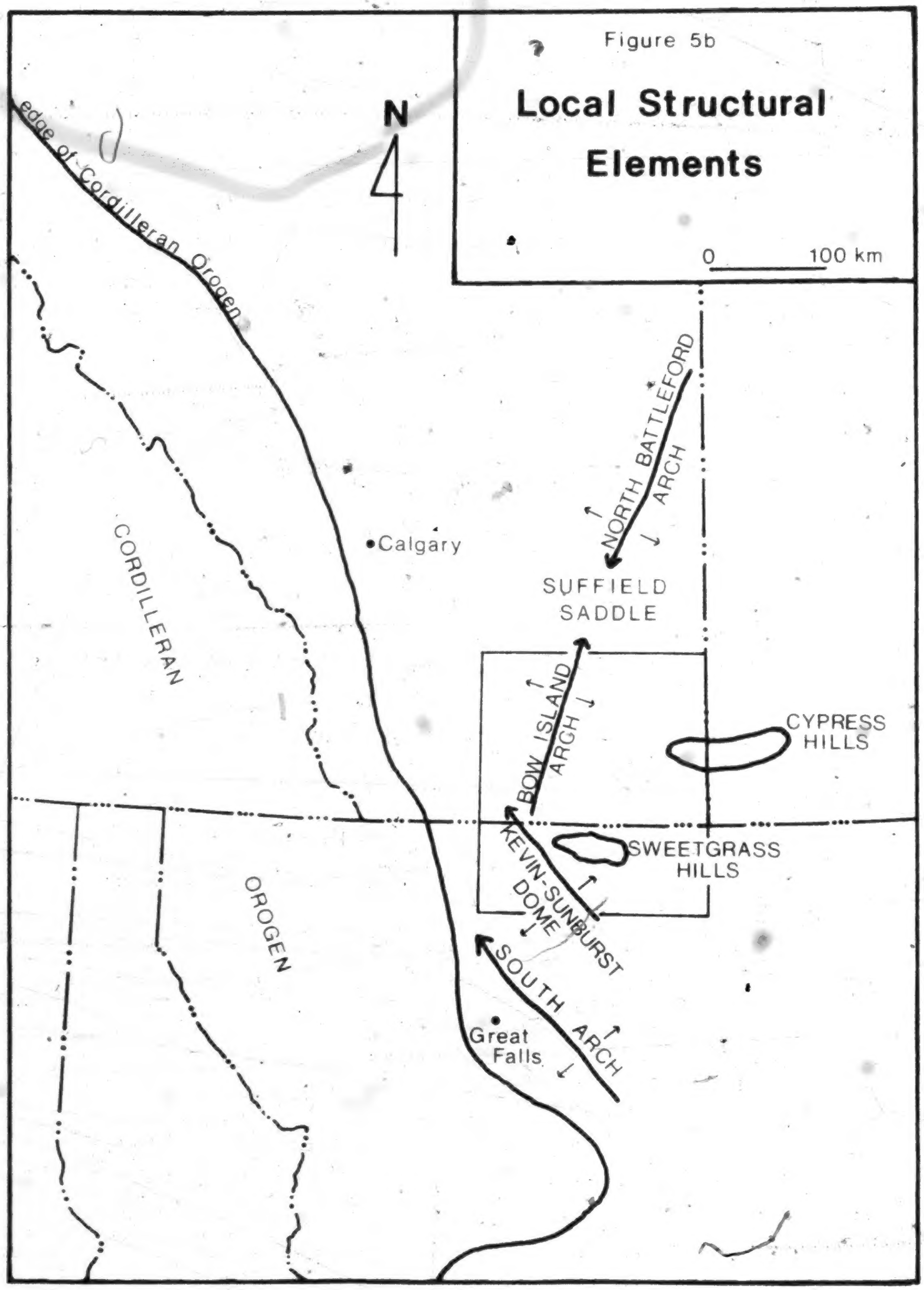


Figure 5b

Local Structural Elements

N
0
100 km
edge of Cordilleran Orogen
Calgary
CORDILLERAN
OROGEN
NORTH BATTLEFORD ARCH
SUFFIELD SADDLE
BOW ISLAND ARCH
CYPRESS HILLS
SWEETGRASS HILLS
KEVIN-SUNBURST DOME
SOUTH ARCH
Great Falls

Sources: Tovell (1958), Herbaly (1974)

uplift as a whole can be related to its situation between two primary basins - the Williston Basin to the east and the West Alberta Basin (a Precambrian basement feature coincident in part with the Alberta Syncline) to the west (Stelck, 1975). The dynamics of basin subsidence have caused the arch area to remain relatively high, as compressional forces resulting from shortening of the basinal basement limit the diameter of a single basin to about 500 km. (Dallmus, 1958).

Some relative uplift along the present Sweetgrass Arch must therefore have occurred as long ago as the time of formation of the Williston Basin, as a result of the geometric constraints mentioned above. Burwash (1963) proposed that north - south lines of weakness, formed during the Precambrian Kenoran Orogeny, may have governed the precise location of the main part of the arch.
Stelck (1975) noted the erosion of Upper Ordovician carbonates over the ancestral Sweetgrass Arch, inferring the presence of a paleotopographic high as old as Early Silurian. Erosional thinning of Jurassic and Mississippian strata over the arch and facies patterns in Middle Jurassic strata (Peterson, 1972) provide definite evidence of some uplift before and during the Jurassic and Early Cretaceous. A regional southward axial plunge, opposite to the present trend, must have been present, as shown by the erosional thinning and truncation of strata to the north (Alpha, 1958; McMannis, 1965; Herbaly, 1974). Bokman (1963) associated

this southerly plunge with general uplift of the Plains which terminated the deposition of Mississippian carbonates.

Major reactivation of the Sweetgrass Arch occurred during the Late Cretaceous and early Tertiary Laramide Orogeny (Tovell, 1958). Compressional forces which formed the thrust-sheet structure of the Rocky Mountains also acted on the craton margin, elevating the Kevin - Sunburst Dome along an axis parallel to the mountain front. As the greatest uplift occurred at compressional foci in the southern part of the area, a northward plunge of the axis of the Sweetgrass Arch resulted, opposite to the previous plunge. Where the magnitude of the northerly plunge became equal to the previous southerly plunge, the Suffield Saddle was formed. To the north of this, the original southward plunge is still expressed in the North Battleford Arch.

Regional stratigraphic correlation shows that the ancestral Sweetgrass Arch greatly influenced sedimentation patterns during the Jurassic and Cretaceous. The stratigraphy also shows, however, that the ancestral arch was not exactly coincident with the post-Laramide arch, a fact which must be considered when comparing stratigraphic patterns with the present configuration of the arch.

B. Williston Basin

The Williston Basin, one of the major structures of central North America, is a stable intracratonic basin in which Phanerozoic sediments have accumulated to a total thickness of 3500 metres in southeastern Saskatchewan, and up to 5500 metres at the basin centre in western North Dakota (Kent and Simpson, 1973). To the north and northwest, the Basin grades into the broad Alberta Shelf (Fig. 5a). As defined by Dallmus (1958), it is a primary dynamic basin, formed as a concentric downbend of the earth's crust.

Few major departures from the large-scale basinal form exist in the Williston Basin. Solution of the Devonian Prairie Salt evaporites is responsible for widespread collapse structures, some of which are important petroleum traps. Intrabasinal arches, such as the Swift Current Platform (Stelck, 1975), formed in response to compressional stresses associated with the active subsidence of the basin, appear to be locally significant in the migration and accumulation of petroleum (Christopher, 1974).

Strata dip markedly off the eastern flank of the Sweetgrass Arch (Fig. 5c), although the study area does not extend to the Williston Basin proper. At the culmination of the Kevin - Sunburst Dome, the top of the Jurassic System occurs at 800 metres above sea level, whereas at the Saskatchewan border, this horizon is found as much as 200 metres below sea level.

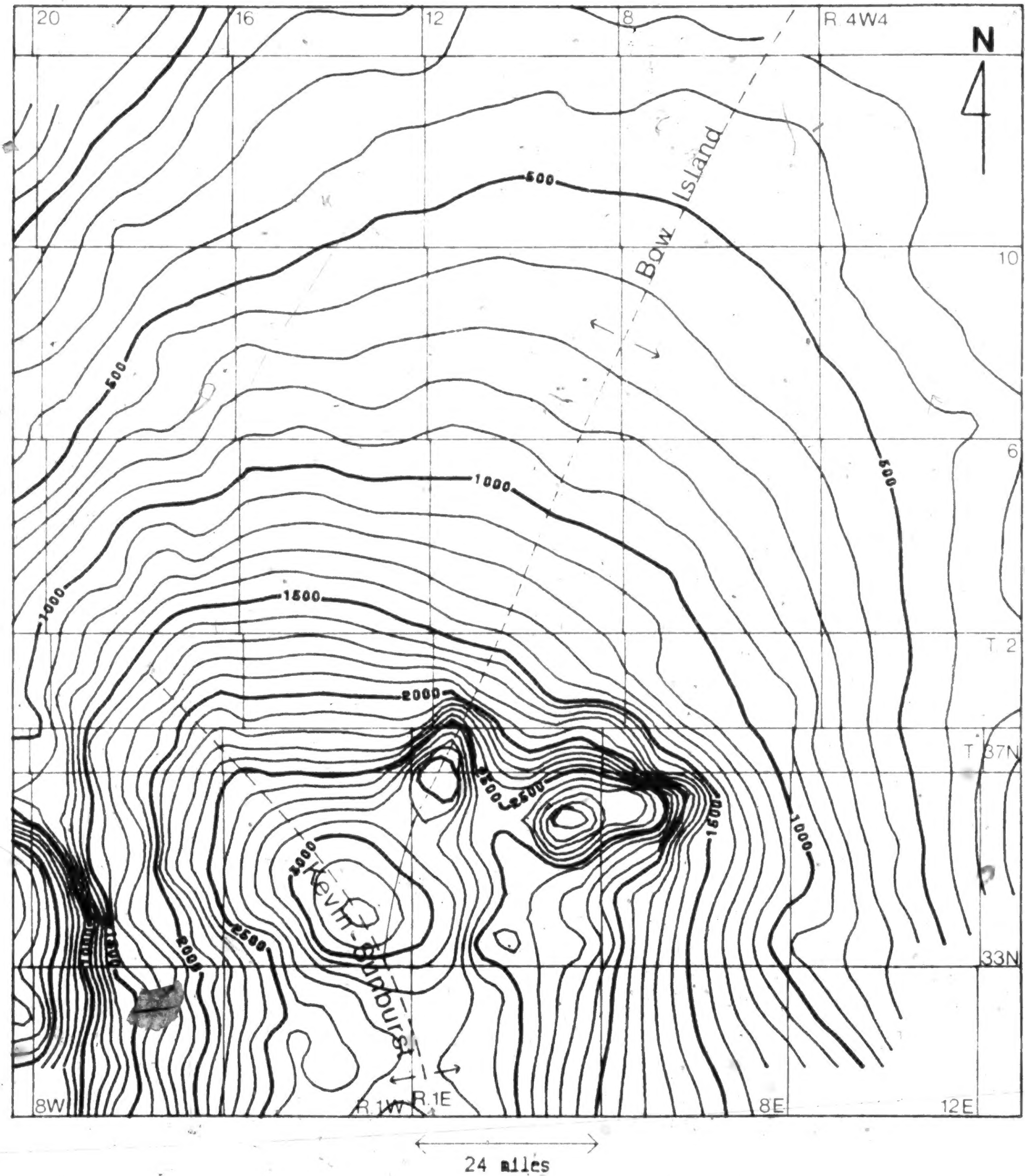

20
16
12
8
R 4W4
N
10
6
T 2
T 37N
33N
8W
R 1W
R 1E
8E
12E
500
1000
1500
2000
2500
Bow Island
Kevin Sunburst
24 miles

Fig. 5c. Structure map, base of Fish Scales zone. Trends of axes of Kevin – Sunburst Dome and Bow Island Arch are shown by dashed lines; solid line joining the two completes trace of Sweetgrass Arch (the arch trend is clearer at larger map scales).

C. Alberta Syncline

Unlike the Sweetgrass Arch and Williston Basin, the Alberta Syncline is a relatively young structure, dating back only to the Late Cretaceous to Early Tertiary Laramide Orogeny. The eastern, west-dipping limb of the syncline is an expression of the dip of the Precambrian basement and the overlying Phanerozoic strata off the edge of the ancient craton (Price, et al., 1981). To the west, Cretaceous strata, structurally thickened by folding and thrusting, form the western, east-dipping limb, which is developed on top of undeformed Paleozoic strata that continue to dip west without interruption (Price, et al., 1981). All the strata discussed here were deposited long before the western limb of the syncline was formed, and the study area includes only part of the eastern, undeformed limb.

Structural dip off the Sweetgrass Arch toward the Alberta Syncline is even more marked than toward the Williston Basin (Fig. 5c). The top of the Jurassic System lies as deep as 350 metres below sea level at the western boundary of the study area, as compared to 800 metres above sea level at the culmination of the Kevin - Sunburst Dome.

D. Minor Structures

Numerous smaller structures are present in southern Alberta and northern Montana. None of these apparently existed during the Jurassic and Early Cretaceous, but they have been of critical importance in petroleum occurrence.

Tovell's (1958) analysis of the Sweetgrass Arch showed that numerous small folds radiate from the Kevin - Sunburst culmination. Russell and Landes (1940) discussed many of these structures and their importance in petroleum entrapment. Relatively few data were available at the time of their report, so that it is now possible to construct a much more detailed structural analysis with present well control.

A closely-spaced group of Tertiary intrusive masses called the Sweetgrass Hills crop out in the east-central part of the study area, south of the international border (Fig. 5b,c). Their origin can be linked to the increased cross-sectional curvature of the Sweetgrass Arch resulting from Laramide compressive forces uplifting the Kevin - Sunburst Dome. Dallmus (1958) showed that the crust would crack to a depth sufficient to allow magma to rise along fractures if a certain critical rate of change of dip across a basin margin was exceeded, which presumably occurred along the axis of the Kevin - Sunburst Dome.

The importance of the Sweetgrass Hills in the context of this study is that they have locally brought Mississippian and younger strata to the surface, as discussed in Chapter I. Kemp and Billingsley (1921) outlined the general geology of the Sweetgrass Hills, and Meldahl and Rice (1966) published a road log for the area.

Capped by the resistant conglomerate of the Cypress Hills Formation, the Cypress Hills rise 700 metres above the

Plains in southeastern Alberta and southwestern Saskatchewan (Fig. 5b). Furnival (1946) described them as anticlinal structures formed by compressive forces associated with the Laramide Orogeny. Russell and Landes (1940) postulated large-scale slumping as the mechanism to explain structural displacement observed in outcrop, but they had insufficient subsurface data to appreciate the amount of local deformation of deeper strata. Present well control shows that faulting of various types displaces Cretaceous, Jurassic, and Mississippian strata in the area.

IV. REGIONAL LITHOSTRATIGRAPHY

The lithostratigraphic scheme arising from this study is summarized in Fig. 6. Detailed analysis was limited to strata from the Upper Jurassic Rierdon Formation through to the Lower Cretaceous Gladstone Formation; the underlying Middle Jurassic Sawtooth and Shaunavon Formations are briefly discussed only to clarify the Rierdon paleogeology and paleogeography. Similarly, characteristics of the overlying Lower Cretaceous Beaver Mines Formation are summarized to elucidate the top boundary of the Gladstone. Sedimentary structures described in this chapter are illustrated in Fig. 7.

A. Middle Jurassic Paleogeology

Commencement of marine sedimentation in the Middle and Late Jurassic marked the end of an extremely long period of erosion and the burial of a major unconformity in western North America. Jurassic deposits overlap progressively older formations from southwest (Permian and Pennsylvanian in southern and central Montana) to northeast (Devonian in Saskatchewan) (Peterson, 1972; Springer et al., 1964). This pattern can be attributed to the previously-discussed southerly tilting of the Sweetgrass Arch area at some time between the Middle Mississippian and Middle Jurassic. In southern Alberta and north-central Montana, the pre-Jurassic subcrop consists entirely of Mississippian strata,

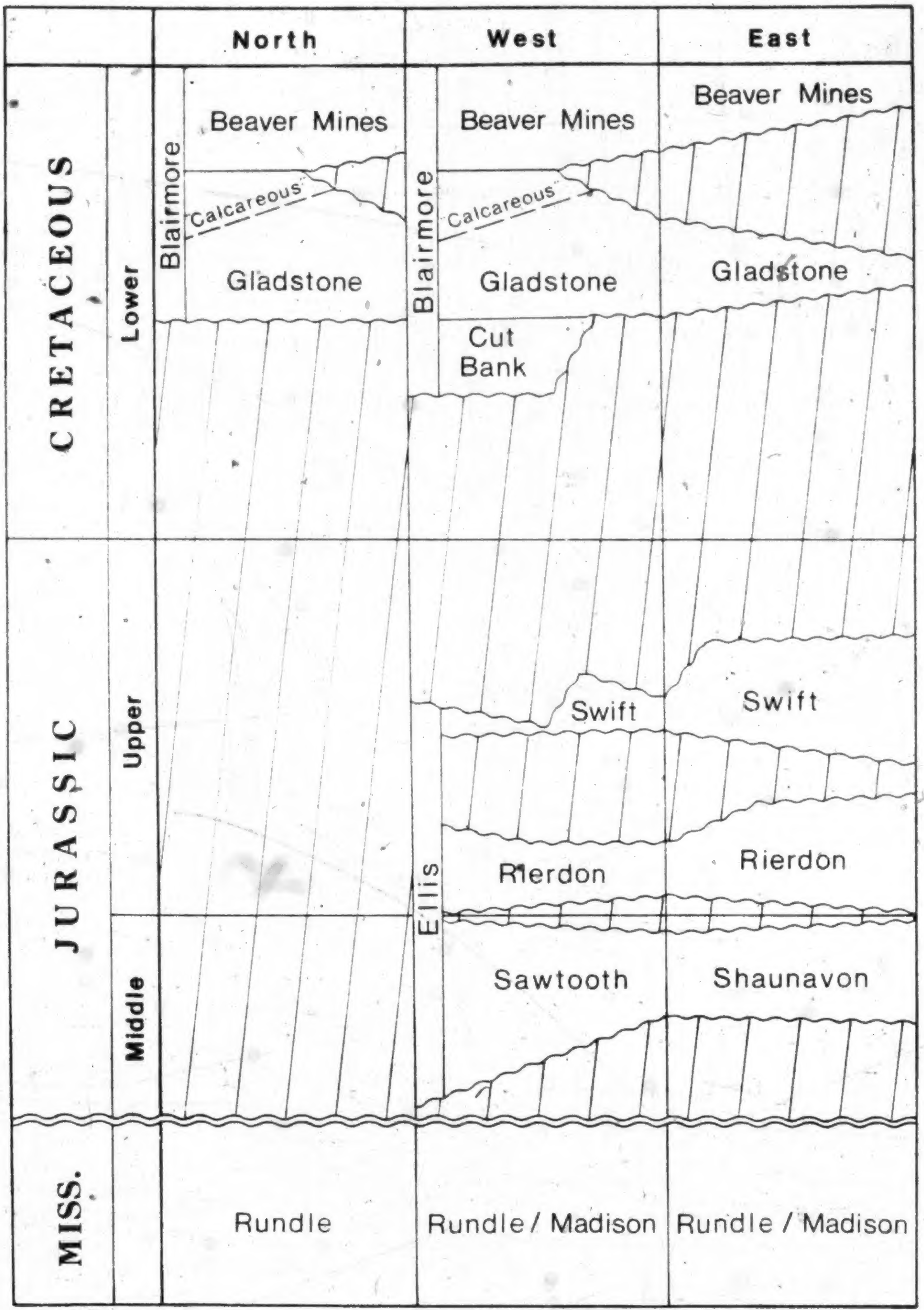

North
West
East
CRETACEOUS
Lower
Blairmore
Beaver Mines
Calcareous
Gladstone
Blairmore
Beaver Mines
Calcareous
Gladstone
Cut Bank
Beaver Mines
Gladstone
JURASSIC
Upper
Middle
Swift
Swift
Ellis
Rierdon
Rierdon
Sawtooth
Shaunavon
MISS.
Rundle
Rundle / Madison
Rundle / Madison

Fig. 6. Lithostratigraphic correlation chart, study area.

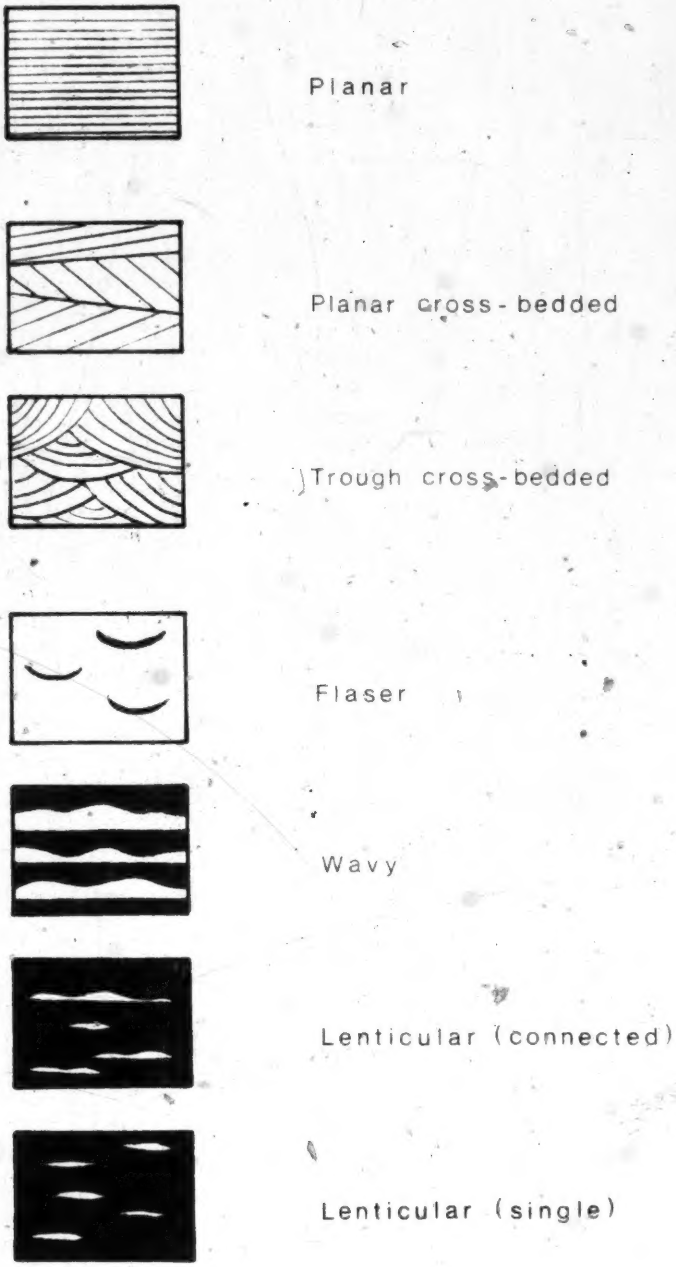

Planar
Planar cross-bedded
Trough cross-bedded
Flaser
Wavy
Lenticular (connected)
Lenticular (single)

Fig. 7. Schematic illustrations of bedding types referred to in text (after Reineck and Singh, 1973). Light-coloured material is sand, dark is mud.

represented by the Rundle Group in Alberta and the Madison Group in Montana. Bokman (1963) analyzed the post-Mississippian unconformity of Alberta in some detail, documenting the deep erosion of the Mississippian carbonates by complex stream systems.

B. Ellis Group

The name "Ellis" was first used for an undescribed rock unit of probable Triassic to Jurassic age mapped by Peale (1893) in southern Montana. Several workers later recognized the Ellis as a formation, but a formal type section was not located and described until 1945 (Cobban, et al.). Cobban (1945) raised the Ellis to group status, and described the three constituent formations: (in ascending order) the Sawtooth, Rierdon, and Swift.

Sawtooth and Shaunavon Formations

Cobban (1945) recognized the type Sawtooth Formation at Rierdon Gulch, Montana (Sec. 23, Twp. 24N, Rge. 9W) (Fig. 1), where it consists of three members:

1. basal quartzose sandstone up to 20 inches thick.
2. dark grey interbedded calcareous and non-calcareous shale, 83 feet thick.
3. calcareous quartzose siltstone coarsening upward to very fine sandstone, 52 feet thick.

The type locality is about 55 km south of the southwest corner of the study area, and lies at the very eastern edge of the disturbed belt (Foley, 1966). In the most southwesterly well examined in this thesis, Montalban De Ruwe #1-A (NENW 33 30N 8W), the Sawtooth can be recognized with confidence. The upper siltstone member is 64 feet thick, the medial shale 70 feet thick, and the basal sandstone about six feet thick; all these thicknesses are within the limits described by Cobban (1945) for this area.

Although the correlative Shaunavon Formation is not part of the Ellis Group, it is discussed here because it is mapped within the study area. The type section is the cored interval from 4682 feet to 4820.5 feet in the Tidewater Eastend Crown #1 well, at 15-11-6-20W3 (Saskatchewan). Milner and Thomas (1954), who named the formation, described two members in the type section:

1. a lower member of cream lithographic limestone, sandy and oolitic at the top, 79.5 feet thick.
2. an upper member of alternating thin, sandy, very fossiliferous limestone beds and calcareous green and variegated shale, 59 feet thick.

Christopher (1974) studied the Shaunavon in detail and correlated it throughout Saskatchewan. His formation top data and well logs from southwestern Saskatchewan have been used to extend the Shaunavon into the present study area.

Stratigraphic names from the American side of the Williston Basin have historical precedence with respect to the Shaunavon, but considerable debate has taken place regarding the validity and scope of Jurassic formations in the northern U.S., so that the exact correlation of the

Shaunavon with the American units is unclear. Consequently, the Canadian stratigraphic scheme is here used on both sides of the border.

The Sawtooth can be correlated across the western part of the study area and the Shaunavon across the eastern part with a high degree of confidence. Although they are obviously equivalent units on the basis of stratigraphic position and fossil content (to be discussed in Chapter 5), their lithologies are sufficiently different to justify the use of the two formation names. In view of the fact that the lithologic change is transitional and not easy to document, a rather arbitrary boundary must be designated, which the author proposes as the crest of the Sweetgrass Arch (Fig. 5c).

The Sawtooth - Shaunavon lithosome thins and is locally absent across the arch (Figs. 8, 10, 11) due to both depositional and erosional factors, as strata from both the top and base of the formations are lost toward the crest. Peterson (1972) interpreted Sawtooth - Shaunavon strata at the crest of the Sweetgrass Arch to represent clean beach sand deposits; in the present study area, the Sawtooth and Shaunavon are much sandier than in surrounding areas. Paleoecological interpretation of the megafauna (Imlay, 1957), microfauna (Brooke and Braun, 1972), and microflora (Pocock, 1972) indicate that the formations were deposited in warm shallow seas which became brackish to fresh near the emergent or near-emergent Sweetgrass Arch.

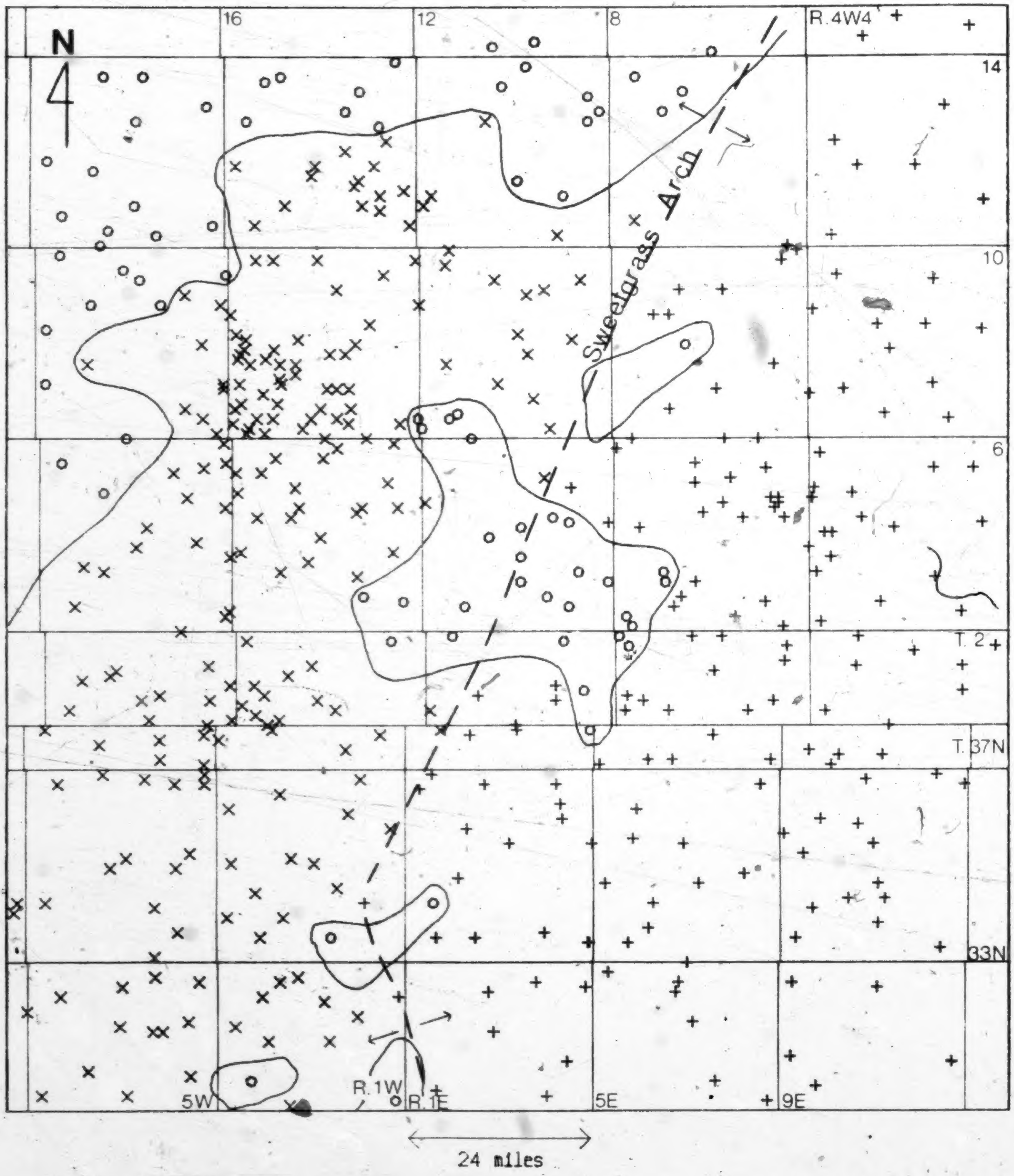

N
16
12
8
R.4W4
14
10
6
T. 2
T. 37N
33N
Sweetgrass Arch
5W
R.1W
R.1E
5E
9E
24 miles

Fig. 8. Pre – Upper Jurassic paleogeology. Circles indicate Mississippian strata, X's Sawtooth Formation, and crosses Shaunavon Formation. Trace of Sweetgrass Arch is indicated by dashed line.

The thickness and lithofacies of the Sawtooth and Shaunavon are affected significantly by the configuration of the dissected surface upon which they were deposited (Bokman, 1963). Documentation of these relationships is outside the scope of the present study, but it is important to note that the relief on the Mississippian surface was greatly reduced by deposition of the Sawtooth and Shaunavon. Temporary retreat of the oceans and generally minor erosion caused removal of the uppermost Sawtooth and Shaunavon strata, as shown in Figs. 9 - 11.

Figure 8 illustrates the resultant pre-Rierdon paleogeology. At least three conditions detract from the quality of this map:

1. Most of the Mississippian inliers are probably larger because of the difficulty in distinguishing thin Sawtooth - Shaunavon beds from detritus of unknown age on the Mississippian surface.
2. The Sawtooth becomes more calcareous and less distinct from the Rierdon in the west-central and northwestern parts of the study area, as illustrated in stratigraphic cross-section S1 - N1 (Fig. 12).
3. The Shaunavon limestone sometimes is not easy to distinguish from the Mississippian carbonates, especially in the extreme northeast.

These effects are fairly minor, and do not significantly affect the Rierdon paleogeology illustrated here.

Rierdon Formation

(a) Type Section and Description

At Rierdon Gulch, Montana (Sec. 23, Twp. 24N, Rge. 9W), the type Rierdon directly overlies the type Sawtooth. Cobban (1945) specifically defined the Rierdon as a lithostratigraphic unit, noting that it is of variable age over the area he studied. Cobban described the type section from oldest to youngest as:

1. medium grey chunky limy shale with a few nodular limestones, 20.5 feet.
2. dark grey fissile, calcareous to almost non-calcareous shale with thin beds of nodular limestone, 33.5 feet.
3. medium grey chunky limy shale with a few thin beds of limestone in the lower part, 43.5 feet.
4. alternating four- to six-inch limestone layers and thicker beds of medium grey chunky limy shale, 39 feet.

More concisely for subsurface correlation purposes, the formation can be divided into three informal members: a basal medium grey-green limy shale with limestone beds, a medial dark grey-green fissile, slightly calcareous to non-calcareous shale with minor limestones, and an upper medium grey-green limy shale with nodular limestones.

(b) Lithology and Environment of Deposition

Only a small amount of core from the Rierdon was studied (Appendix A, Fig. 16), because such thick shale sequences are rarely cored in the course of petroleum exploration; in most cases, only short cores from the top of the formation were taken. Beds from all levels can be found in different cores, however, because post-Rierdon erosion has removed varying amounts of the formation.

All three informal members of the Rierdon can be recognized over large areas (Figs. 9 - 13), as their lithologies are remarkably homogeneous regionally, although a greater overall proportion of shale than noted in the type section was apparent. Disseminated and occasionally nodular pyrite is ubiquitous. Only two minor variations from the type section lithologies were noted. Thin (less than one foot) bentonite beds were found in two wells - 6-31-6-8W4 and 6-4-7-6W4. The significance of these beds remains undetermined, as they have not been cored or described elsewhere, and they are too thin to appear on geophysical logs. Similarly, the significance of layers of silt-sized siderite grains a few inches thick in a few cores could not be determined from the limited data available.

The fossil content of the Rierdon clearly indicates a shallow marine environment of deposition, with some slight deepening at the craton edge suggested by minor changes in faunal composition. Imlay (1947, 1953, 1957, 1962) described a great variety of shallow marine megafossils, strongly dominated by molluscs, in the Rierdon and correlative strata. Very diverse ostracod and foraminifera assemblages documented by Brooke and Braun (1972) in southwestern Saskatchewan and north-central Montana also indicate shallow marine conditions with normal salinity.

These authors interpreted a decrease in faunal diversity upwards in the section to result from a gradual shallowing of the sea. The Rierdon microflora, described by Pocock (1972), also typifies shallow marine shelf conditions.

In conclusion, the Rierdon Formation was deposited in a broad shallow sea which received no coarse clastic debris. Fluctuations in the relative rate of deposition of carbonate and terrestrial muds led to the alternation of argillaceous and calcareous beds in the formation. The record of abundant life indicates well-oxygenated conditions above the sediment - water interface, but ubiquitous pyrite denotes more reducing conditions existed within the mud itself.

(c) Log Character

As core data are scarce, the lithologic nature of the Rierdon almost always must be inferred from the character of geophysical log responses. The entire formation is shaly and has negligible porosity and therefore does not deflect the spontaneous potential curve. Relatively high resistivity, low gamma emission, and high acoustic velocity values characterize the thin limestone bands present in much of the formation. Rapidly fluctuating, spiky log patterns are thus produced where limestones and shales are intimately interbedded in the upper and lower members, while more subdued gamma, sonic, and resistivity patterns are characteristic of the more argillaceous middle member. Typical log signatures are illustrated in the stratigraphic cross-sections (Figs. 9 - 13).

(d) Correlation

The Rierdon can best be characterized by considering its variations along the south - north and east - west cross-sections, then examining its nature and distribution over the entire study area.

In the most southwesterly well in the study area (NENW 33 30N 8W), closest to the type locality, the Rierdon is 102 feet thick, 34 feet thinner than at the type section. Cobban's three informal members can be recognized here, the basal calcareous member being 30 feet thick, the medial non-calcareous member about 20 feet thick, and the upper calcareous member 52 feet thick. Most of the thinning was the result of erosion prior to the deposition of the overlying Swift Formation, as indicated by the reduced thickness of the upper member.

Stratigraphic cross-section W2 - E2 (Fig. 10) and the corresponding structural section W2S - E2S (Fig. 14) best illustrate the behaviour of the formation along a west to east line. The Rierdon can be correlated with confidence northward from Township 30N (Montana) to 14-33-1-19W4 (Alberta), the westernmost well in W2 - E2, although it becomes increasingly difficult to distinguish from the upper silty member of the Sawtooth north of this point. From 14-33-1-19W4 east to 2-4-1-17W4, the Rierdon thins from 83 feet to 42 feet, primarily because of the marked erosion which preceded the deposition of the overlying Cut Bank

Sandstone. The Rierdon thickens again to the east, although only gradually to about 120 feet at the present crest of the Sweetgrass Arch, which runs between 6-1-1-11W4 and 7-18-1-12W4 on this section. East of the crest of the arch, the formation thickens to a maximum of 180 feet and maintains a fairly uniform thickness east of Range 7W4.

East of the 6-29-1-8W4 well, the top of the Rierdon is taken at the "Rierdon Shoulder", a distinctive resistivity, gamma, and sonic marker. The shoulder marks the top of intercalated calcareous shales and argillaceous limestones of the upper limy member where it lies below the non-calcareous shales of the lower Swift member. Careful examination of the logs from 7-14-1-6W4 east to 10-8-2-1W4 (Fig. 10) shows that the shoulder rises stratigraphically to the east, and that it is thus an expression of the upper Rierdon lithologies in general; it does not mark a particular horizon within the formation.

Considerable debate has taken place regarding the validity of the Rierdon shoulder as a marker for the top of the Rierdon Formation. Most notably, Peterson (1957b) argued that a marker much higher in the section should be used. He supported this assertion with four points:

1. "[The Rierdon shoulder] is not consistent with the definition of the [Rierdon] in the type area.
2. Occurs within a unit containing a distinct fauna characteristic of the Rierdon ...

3. The disconformity that separates the Swift and Rierdon in the type area is located some distance above the 'shoulder'.
4. The overlying shale section is not believed to be equivalent to the lower Swift shale of the type area."

A major problem with Peterson's arguments is that he considered the Rierdon Formation to extend eastward into the centre of the Williston Basin. As will be discussed in Chapters V and VI, a considerable section of strata, thickening toward the basin centre, was deposited in the Williston Basin during the time of the Rierdon - Swift depositional hiatus in the study area. Some of these strata can be included in the Rierdon, but a different system of stratigraphic nomenclature is required to the east where different lithotypes were deposited. Christopher (1974) documented the eastward addition of section at the top of the Rierdon, and continued to use the Rierdon shoulder as the marker for the top of the formation well east of the Alberta - Saskatchewan border, showing it to rise stratigraphically in that direction. Further east, where the Williston Basin nomenclature takes effect, the Rierdon shoulder is not an important marker. Peterson's third and fourth arguments are effectively refuted by use of the Williston Basin nomenclature. His second argument does not apply to a lithostratigraphic unit such as the Rierdon Formation, which was defined specifically on lithological character. Peterson's first argument is incorrect in that it has been demonstrated here that in the study area, the shoulder indeed marks the top of a sequence of strata which corresponds very closely with the sequence in the type section.

Lithologically, the Rierdon is quite uniform across section W2 - E2. The three-member subdivision of the formation can be distinguished in 14-33-1-19W4 (Alberta). East of 6-23-1-10W4, the resistivity curve is very distinctive, showing the basal limy member to be from 50 to 70 feet thick, the medial non-calcareous member from 20 to 30 feet thick, and the upper limy member from 70 to 100 feet thick. In the intervening area, across the Sweetgrass Arch, the upper limy member and most or all of the medial member have been removed by erosion. The elevation of the arch was sufficient, therefore, to cause significant erosion during the short regressive interval between Rierdon and Swift deposition.

A sequence of lithologies in the Rierdon similar to that observed in W2 - E2 can be traced across stratigraphic cross-section W3 - E3 (Fig. 11). In this case, however, the formation is generally thinner than it is to the north; only in the extreme east (SWSW 35 31N 12E) does it thicken to 170 feet. Most of the difference is because of the thinner basal limy member, which is about 30 to 40 feet thick in the eastern wells, as opposed to 50 to 70 feet in the eastern half of W2 - E2. The southern three wells of stratigraphic section S2 - N2 (Fig. 13) illustrate the thinning of the basal member to the south; further to the south, Cobban (1945) noted the thinning and eventual loss of the basal member east from the type section. He mapped the southern pinchout of the entire formation to pass as close to the study area as Township 28N, Range 1W. Evidently the South Arch, the southernmost component of the Sweetgrass Arch, had sufficient topographic relief at the time of Rierdon deposition to cause depositional thinning and eventual pinchout of the formation. As there is no evidence of an influx of coarse clastic debris from the south, the arch was evidently not a high-relief source area.

In south - north stratigraphic cross-section S2 - N2, the Rierdon thins to about 135 feet in Townships 34N and 35N before thickening again to approximately 170 feet in Township 36N (Montana) to Township 1 (Alberta). This thinning appears to be the result of extensive local erosion prior to deposition of the overlying Swift Formation. North from 7-14-1-6W4, the upper member gradually thins beneath the Swift, indicating a general northward bevelling prior to Swift deposition. The Rierdon thins more rapidly north of Township 12, reflecting the removal of both Swift and Rierdon strata by pre-Mannville erosion.

Cross-section S1 - N1 (Figs. 12, 15) also shows the general northward bevelling of the Rierdon. Sub-Blairmore erosion is more evident in this section, as the Swift is completely eroded north of 4-32-6-14W4. In addition, the absence of Cut Bank and Gladstone strata over much of the northern half of the section indicates that a large area was exposed and experienced erosion or nondeposition during most of the Late Jurassic and Early Cretaceous.

(e) Regional Analysis

The present distribution of the Rierdon Formation is summarized in the isopach map (Fig. 16). Three major features stand out:

1. A broad platform of relatively thick Rierdon makes up the southeastern half of the map. The formation is thickest in the middle of the area and thins to the north and south; on the northwest the platform is bounded by the 100-foot isopach line.
2. A sharp erosional thinning of the formation along a north-south trend is centred on Range 17W4 in Alberta and Ranges 5W - 6W in Montana, and is here referred to as the Cut Bank Valley.
3. The formation thins in the northern half of the area to a pinchout in Townships 12 to 15.

A few important controls of these features can be outlined. The emergent South Arch caused the formation to thin in the southern part of the study area, but the low northern part of the ancestral Sweetgrass Arch had less effect on the pattern of deposition. There is no indication of an original northern shoreline, due to the southward tilting of the area combined with northward bevelling by pre-Swift and pre-Blairmore erosion. The effects of

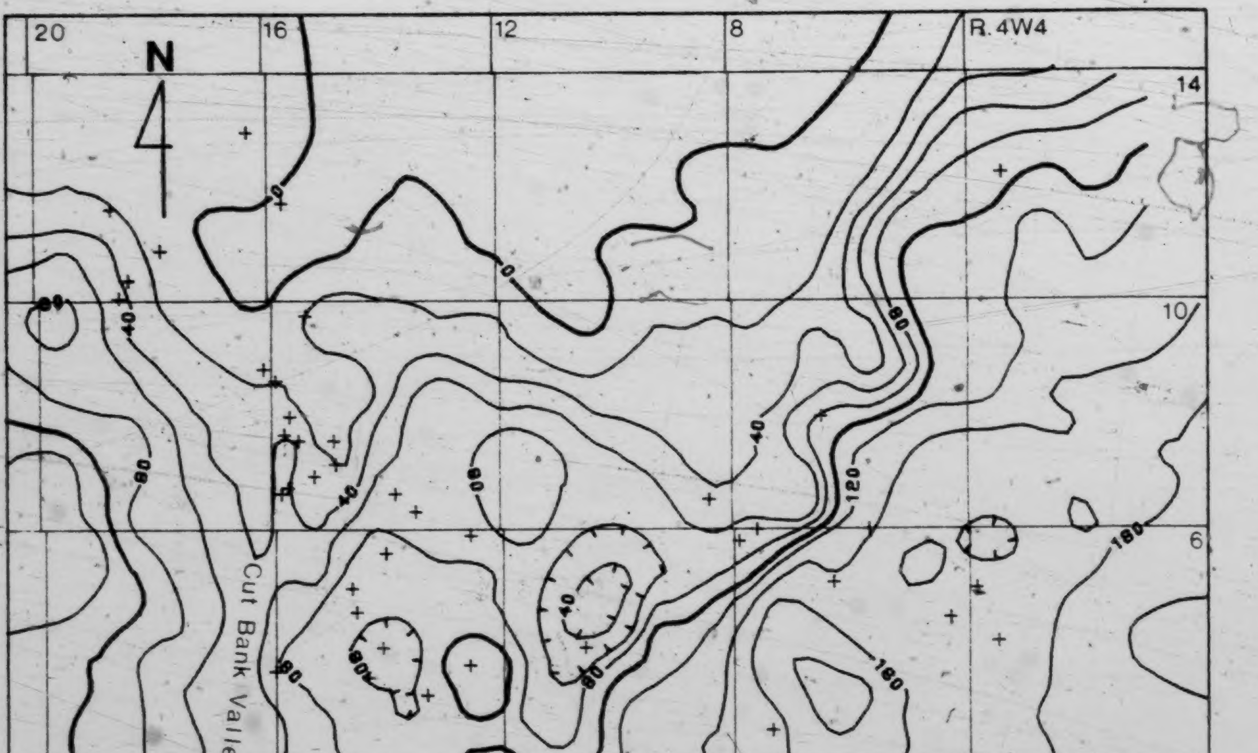

20
16
12
8
R.4W4
N
14
10
6
T. 2
T. 37N
33N
5W
R.1W
R.1E
5E
9E
Cut Bank Valley
0
40
80
120
160
180
24 miles

Fig. 16. Isopach map, Rierdon Formation. Crosses indicate wells with core control; see Fig. 3 for remaining control points. Contour interval = 20 feet.

pre-Swift erosion are manifested primarily as minor variations in thickness in the southeastern platform area, and in thinning of the Rierdon across the Sweetgrass Arch. Pre-Blairmore erosion in the northern and western parts of the study area caused general northward bevelling and significant local channelling which removed the Swift and much of the Rierdon, particularly in the Cut Bank Valley. Other unpublished work by the author shows that the entire northern border of the Rierdon is dissected by sharply-bounded Blairmore valleys, although this is not apparent on the regional isopach map. More well control and interpretative contouring would show the presence of some of these valleys.

Swift Formation

(a) Type Section

The type section of the Swift Formation is located on the north shore of Swift Reservoir, Montana (NE 1/4, Sec. 27, Twp. 28N, Rge. 10W), in the easternmost Cordilleran thrust sheet bringing Jurassic and Mississippian strata to the surface. As described by Cobban (1945), the Swift consists of a lower shale member and an upper sandstone member. The shale, 54.5 feet thick, is dark grey, non-calcareous, and finely micaceous; it contains minor pyrite, some hard siltstone streaks, and large rusty brown-weathering calcareous concretions. A few inches of highly glauconitic shale with water-worn belemnites and black chert pebbles form a distinctive basal marker. The

80-foot-thick sandstone member is composed primarily of fine quartz grains with subsidiary grey and black chert, and is flaggy, ripple-marked, bioturbated, and contains abundant black-grey fissile shale partings and accessory glauconite, muscovite and coaly fragments. Another glauconitic chert-belemnite conglomerate up to seven inches thick marks the contact between the two members.

At the type locality, the Swift disconformably overlies the Rierdon, and is unconformably overlain by mudstones, siltstones, and sandstones of continental origin, the age of which has not been clearly defined. Cobban (1945) assigned this continental sequence to the uppermost Jurassic Morrison Formation, but three samples collected in the interval by the author yielded palynomorphs of Aptian age. This problem is discussed in more detail in the following section on the Morrison Formation.

(b) Lithology and Fossil Content

The lower shale member of the Swift conforms closely to Cobban's (1945) description over the entire study area. Glauconite is sometimes concentrated in isolated small lenses, and minor woody plant debris was often observed. A basal chert-belemnite conglomerate was found only once, in the McColl - Frontenac Union 9A-22-3-8W4 well, at 2920 feet (Plate 1a). Scattered dark chert pebbles were found in the shale in some other wells, but not in sufficient quantities to constitute the marker bed.

In contrast, the upper sand member is not as homogeneous, and does not closely resemble the type section over most of the study area. The term used by many geologists and drillers to describe the member is "ribbon sand", referring to a wide range of interbedded sandstone, siltstone, and mudstone lithologies. In gross composition, the ribbon sand varies from 95% mud and 5% silt to almost 100% clean medium-grained sandstone. According to the classification of Reineck and Singh (1973), all lithotypes from lenticular bedding with single flat lenses through wavy bedding to cross-bedded sandstone with flasers are represented in the core studied (Fig. 7; Plates 1b - 2c). Coarser siltstone and sandstone beds often show evidence of loading on underlying mud layers, and reactivation surfaces are also common (Plates 1b - 2b); these features indicate rapid alternation of current and wave power.

The mud-sized component of the ribbon sand closely resembles the underlying shale member. In most cases, however, the mudstone in the ribbon sand is siltier, more micaceous, contains some amber, and exhibits larger and more abundant fragments of coalified woody plant debris. The colour of the mud component is the basis for a subdivision of the ribbon sand: where the mud is medium to dark grey, the rock is called "dark ribbon sand"; where it is light grey to grey-green, the term "light ribbon sand" is used. Severe oxidation, which removed nearly all the organic material, pyrite, and glauconite originally present, is responsible for the light colour. In general, the light ribbon sand exhibits a greater gross percentage of coarse clastic material than does the dark ribbon sand (Plate 1c). The light ribbon sand always overlies the dark, usually but not always with a sharp contact.

Quartzose siltstone with very minor dark and light chert grains most commonly makes up the coarse component of the ribbon sand. Where the coarse fraction is more abundant than the mud, it coarsens to a very fine- to medium-grained sandstone and becomes more lithic with the addition of dark grey to black chert and a small percentage of rock fragments (Plate 4a). Grain size variations of the coarse fraction are usually quite gradational, although lenses and beds of coarser extralitharenite can abruptly intertongue with silt and fine sand (Plate 2a).

Pyrite is abundant in the dark ribbon sand, occurring both as disseminated grains and as nodules up to three centimetres in diameter (Plate 1d). Glauconite is rare, appearing most often in the lower part of thick dark ribbon sand sequences. In the light ribbon sand, siderite pellets about 1 mm in diameter are very common, occurring disseminated throughout the rock, or less commonly as detrital concentrations in silt or sand lenses.

The contact between the shale and ribbon sand members is preserved in only two of the cores studied - CMG Black Butte 5-17-1-8W4 (p. 244) and Conrad Province 12-36-4-15W4 (p. 265). In both cases, the contact is rather indistinct, and separates silt-streaked shale below from ribbon sand with thin flat lenticular silt beds above. No chert-belemnite conglomerate was observed in either case. Analysis of the geophysical logs shows that this contact is often gradational, especially where the shale member is thickest. Coarse ribbon sand does abruptly overlie the shale in a number of wells however, especially where the lower member is thinner than 15 feet.

Bioturbation is nearly ubiquitous in the dark ribbon sand (Plate 1d), but is much less common in the light ribbon sand. Tubular burrows up to 3 mm. in diameter, branching and cutting across beds at all angles, make up most of the trace fossils. The density of burrowing activity is extremely variable, but it appears to peak where the mud-sized component makes up 25 - 50% of the rock, although burrows may not be as easily detected where the mud percentage is lower. Rarely is the burrowing so intense that the original bedding is completely destroyed. All burrows are tentatively assigned to the genus Chondrites, by comparison with illustrations and photographs in Chamberlain (1978). Both Chamberlain (1978) and Seilacher (1978) showed Chondrites to occur in a wide variety of marine environments, hence its presence is useful only as an indicator of marine conditions.

Other fossil evidence indicates that the Swift was deposited under primarily shallow marine conditions, and all fossil groups suggest shallowing toward the top of the formation. A shallow marine megafauna dominated by molluscs was documented by Imlay (1947, 1957); most notable is the presence of the pelecypod Mytilus in western Montana and Wyoming, which suggests littoral conditions. Microfaunas similar to those characterizing the Rierdon are found in the Swift and correlative strata of the Williston Basin, but the Swift assemblages are less diverse, indicating a more restricted nearshore environment (Brooke and Braun, 1972). Continued shallowing, decreased salinity, and increased turbidity are evident in the upper part of the Swift, as the microfaunal assemblage becomes restricted to shallow-water, brackish-tolerant agglutinated foraminifera. The microflora record the same trend of decreased marine influence upward from the base of the Swift (Pocock, 1972), a trend also noted in palynological samples examined for this thesis.

No diagnostic fossils were recovered from the light ribbon sand in the course of the present study. Evidently, the continued shallowing trend eliminated all marine fossil indicators in these strata.

(c) Environment of Deposition

As noted in part (b), the lithology and fossil content of the Swift denote a shallow marine environment of deposition. A shallow marine continental shelf depositional model, which depends on storm activity to provide episodic influxes of coarse sediment, can account most satisfactorily for the distribution and nature of the Swift and its equivalents.

Brenner and Davies (1974) proposed a regional depositional model for Oxfordian sedimentary rocks of the western interior of the United States south of the study area (Fig. 17). They concluded that a mud facies, including the shale member and the least sandy sections of the ribbon sand member of the Swift, was deposited under widespread homogeneous low-energy shallow marine conditions in a broad epicontinental seaway. A nearshore marine sand facies was deposited at the western edge of the seaway flanking the source area; the type locality of the Swift is included in this nearshore facies. As previously mentioned, megafaunal occurrences support the interpretation of a nearshore environment of deposition to the west (Imlay, 1947, 1957).

A marine bar-sand facies, capping the mud facies over the entire study area and including the dominantly sandy sections of the ribbon sand, was laid down during the subsequent progradational regression. Submarine sand bars, consisting largely of trough cross-bedded sandstones (Fig. 7; Plate 2c), were separated by muddy interbar areas, where much of the fine sediment winnowed from the bars was deposited in wavy- and lenticular-bedded lithotypes. Brenner (1980) proposed that coarse clastic sediment was carried onto the shelf by currents generated by major storms acting in conjunction with flood-stage flow jets from rivers flowing off the westerly source area. Strong storm surges triggered the deposition of coarse coquinoid sandstone beds, which were observed by this author in northern Wyoming but

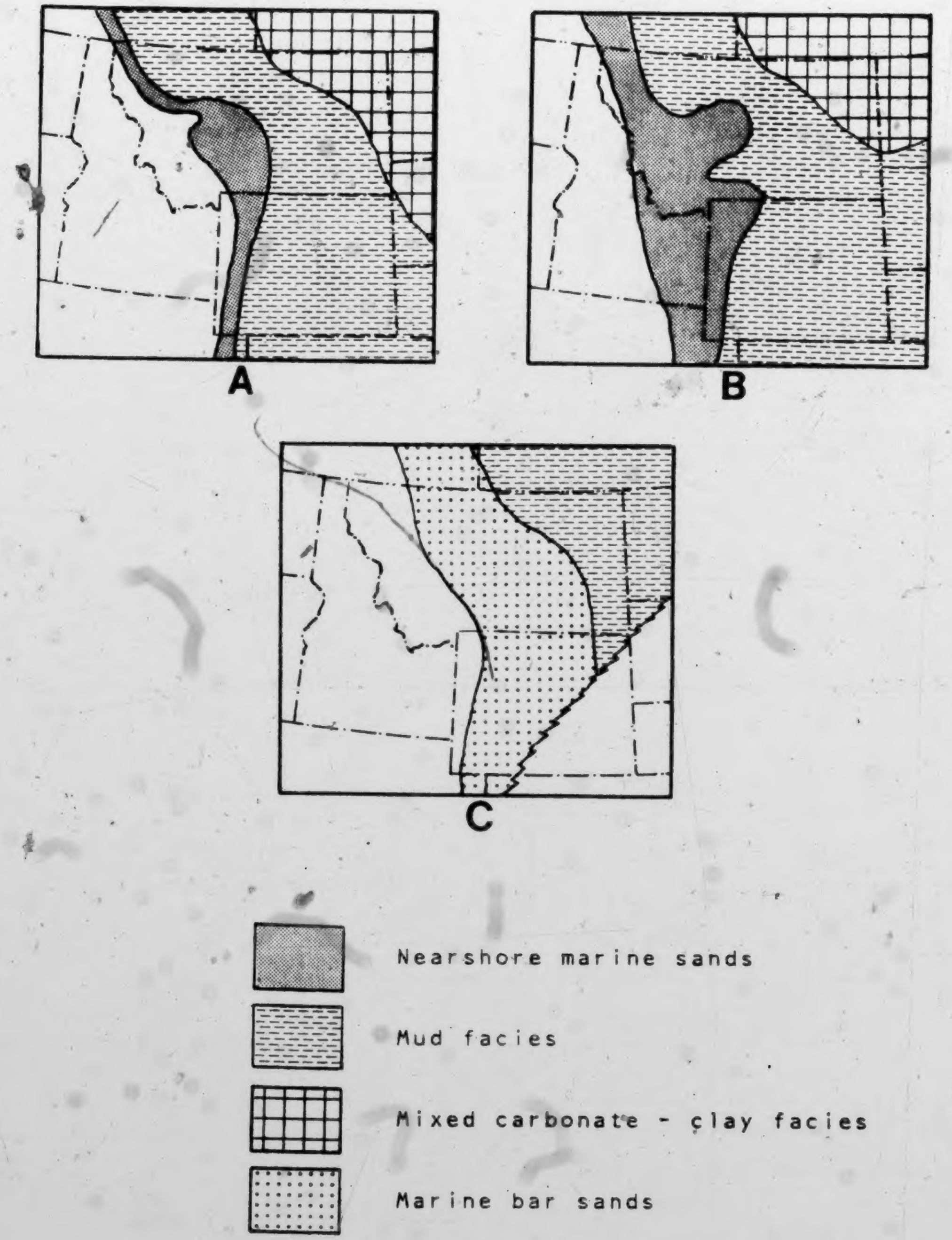

A
B
C
Nearshore marine sands
Mud facies
Mixed carbonate - clay facies
Marine bar sands

Fig. 17. Regional paleogeography and depositional model for western interior United States during Oxfordian time: A - early transgressive phase; B - maximum transgression; C - regressive phase (after Brenner and Davies, 1974).

not in the study area.

Similar lithotypes have been interpreted as "marine-bar sandstones" in the 'J' interval of the Cretaceous Dakota Sandstone of Nebraska by Exum and Harms (1968), and as "shelf sandstones" in shallow Cretaceous sands of the northern Great Plains by Rice and Shurr (1980). Hallam (1975) criticized such interpretations, with specific reference to the Brenner and Davies (1974) model; he suggested that such a widespread distribution of very uniform shallow marine deposits could also be explained by the diachronous deposition of subtidal dunes along a prograding shoreline, although he did not propose any more specific explanations.

De Raaf _et al_. (1977) described strata virtually identical to the Swift ribbon sand member from the Lower Carboniferous Kinsale Formation in County Cork, Ireland. They concluded that wave action was the most important process in the generation of the observed bedforms. Silt and sand were dropped from suspension after being entrained by storm waves and currents, and were often reworked by these same waves. They classified the sequences of lithotypes into four categories: coarsening-upwards (CU), fining-upwards (FU), coarsening- then fining-upwards (CUFU), and random sequences. The successions of sequences observed led them to conclude that deposition took place in an area of shallow quiet water where mud was normally deposited, but which periodically experienced higher energy conditions which introduced coarser sediments and deposited them in various types of longshore shoals. Two important conclusions regarding the environment of deposition of the Kinsale Formation were reached by De Raaf _et al_. (1977): the area experienced generally low wave energy with occasional storms; and a wide range of energy conditions existed, but storm energies were damped by the muddy character of the platform sediments.

The sequence of events summarized by Brenner and Davies explains the general succession and distribution of lithotypes in the Swift and equivalent units, whereas the more complete sedimentological analysis of De Raaf _et al_. provides the basis on which individual sections may be interpreted and lays the groundwork for more detailed reconstruction of sedimentary environments. Comparable thicknesses of strata are present in each case, and all the lithotype sequences found in the Carboniferous sections are present in the Swift, as illustrated by the following examples.

1. Coarsening upward (CU): Core - CMP Coutts 3-13-1-13W4, 2590-2618 feet (Appendix A, p. 248); Log - Energy Reserves Van Auken NWSE 14-30N-4W, 2469-2547 feet (Fig. 11).
2. Fining upward (FU): Core - No clear core descriptions of entire Swift fining upward; Log - CMG Lait 6-23-1-10W4, 2902-2976 feet (Fig. 10).
3. Coarsening then fining upward (CUFU): Core - CMG Black

Butte 5-17-1-8W4, 2906-2970 feet (App. A, p. 244); Log - Pan Am Olson #1 NE 10-36N-8E, 3083-3186 feet (Fig. 13).

4. Random sequence: Core - Cardinal State Darrow SENE 8-37N-5E, 2896-2926 feet (App. A, p. 243); Log - Whitehall Comrey 7-14-1-6W4, 3302-3380 feet (Figs. 10, 13).

De Raaf *et al*.'s (1977) study encompasses a much smaller area than is covered by the Swift, but it appears that the depositional model could be applied over a larger area, given a sufficiently broad shelf and an adequate sediment supply. Some diachronism of deposition resulting from progradation probably occurred, which helps to explain the homogeneity of the facies over such a large area.

One major feature of the Swift Formation not found in the Kinsale Formation is the highly-oxidized, light-coloured ribbon sand. Wave power and flow rates during deposition of the light ribbon sand were probably only slightly higher than during deposition of the dark ribbon sand, as similar lithotypes are observed, albeit with a greater proportion of sand and silt. Deposition was more rapid, as indicated by the increased proportion of coarse sediment and decreased abundance of *Chondrites* burrows (Chamberlain, 1978). Some sections of dark ribbon sand which lack glauconite and yield transitional to non-marine microfossil assemblages may represent intermediate conditions.

Siderite-bearing light ribbon sand lying directly over the pyrite-bearing dark ribbon sand is analogous to successions in the Coal Measures of Yorkshire described by Curtis and Spears (1968), which they interpreted to be the product of more rapid deposition of the upper strata. Sulphate-reducing bacteria could not produce sulphur sufficient rapidly to maintain pyrite formation, hence siderite was precipitated in the upper part of the section during diagenesis. Actual emergence during deposition of the light ribbon sand seems unlikely, but sedimentation probably occurred less episodically, so that oxidizing conditions were maintained at the sediment-water interface.

In summary, deposition of the Swift Formation began with a marine transgression over the entire study area. A basal chert-belemnite conglomerate and scattered dark chert pebbles were deposited in some areas, but otherwise, a very homogeneous dark glauconitic marine shale accumulated over a broad shallow shelf. Increased coarse clastic influx and progradational shallowing of the sea led to deposition of the ribbon sand member. Sand and silt from a rising westerly source area were entrained by storm waves and currents, were dropped from suspension over the broad, dominantly muddy shelf area, and were reworked by waves and currents associated with the same storms into a variety of sand bodies, separated by muddy interbar areas. Reducing conditions caused glauconite to form and coalified wood fragments and abundant disseminated organic material to be preserved. Further progradational shallowing led to the spread of more oxidizing conditions and a slight overall increase in wave power and flow rates, producing the transitional to highly oxidized light ribbon sand.

(d) Log Character

A wide range of geophysical log responses are produced by the variable lithology of the Swift Formation. With the aid of 62 cores penetrating at least part of the formation (Appendix A, Fig. 18), however, the Swift can be distinguished with confidence in most cases.

The basal shale member, where well developed, exhibits the distinctive log signature of a dark shale: the spontaneous potential curve is flat and runs directly on the shale line, while the resistivity is uniformly very low. The gamma log shows a very steady high gamma ray count, and a low acoustic velocity is indicated by the sonic log. Where an abnormally large amount of silt is present and where the shale grades upward to the ribbon sand member, the logs gradually assume a character more indicative of siltstone. The spontaneous potential curve is the least responsive to such variations, requiring about 20 - 30% silt or sand content before deflecting significantly from the shale line.

A large range of log responses characterize the ribbon sand member, which, as previously discussed, includes all lithologies from silty shale to clean medium-grained sandstone. At the shaly end, the log curves grade into the responses described for the shale member, whereas the cleanest sand bodies exhibit classical sand responses, most characteristically low gamma readings and up to 60 mV negative spontaneous potential deflections. Resistivity and sonic responses are more variable, as they are more strongly governed by fluid composition and degree of cementation. The bulk of the ribbon sand member, which is composed of the lenticularly-bedded lithotype, exhibits "cylinder-shaped" intermediate log responses normally associated with siltstones.

Numerous small-scale variations in sand and silt content produce rather jagged curves, making it difficult to pick a boundary between the shale and ribbon sand members in many cases, especially where the shale member is thicker than 40 feet. The somewhat arbitrary division of the members which results must be taken into account as a source of error when interpreting the isopach maps.

(e) Correlation

Unlike the Rierdon and Sawtooth Formations, the Swift is not closely comparable to the type section in the most southwesterly well of the study area (NENW 33 30N 8W (Montana)). Pre-Blairmore erosion in the Cut Bank Valley has removed the entire ribbon sand member in this well, leaving only 47 feet of the basal shale member, which is identified by its stratigraphic position between the Rierdon and the overlying Cut Bank Sandstone, and by core data from the correlative interval in the Shell Tribal (SWSW 28 34N 8W) well.

To the east of the NENW 33 30N 8W well in stratigraphic cross-section W3 - E3 (Fig. 11), the Cut Bank Valley cuts further down section and completely eliminates the Swift. East of the sharp eastern boundary of the valley, from Range 4W to the eastern edge of the section, the Swift increases gradually in thickness from 80 feet to about 140 feet. The shale member is thin west of Range 8E, reflecting onlap onto the remaining low relief of the ancestral Sweetgrass Arch. The ribbon sand member does not appear to be similarly affected, although later erosion may have obscured the depositional thinning.

Stratigraphic cross-section W2 - E2 (Fig. 10) presents a more complex picture. Removal of the Swift under the Cut Bank Valley is illustrated in the interval from 14-33-1-19W4 (Alberta) east to 4-2-1-16W4. The formation thickens rapidly east of the valley, but is truncated sharply by another erosional valley from Range 12W4 to Range 9W4, most notably in 6-1-1-11W4. East of the eastern valley margin, the Swift thickens rapidly to about 90 feet, and varies between 80 and 110 feet to the eastern end of the section. General eastward thickening from the Sweetgrass Arch, evident especially in the shale member, and variable pre-Blairmore erosion control the thickness along this line of section.

The south - north stratigraphic cross-sections demonstrate northward bevelling of the Swift by pre-Blairmore erosion, which occurs at a fairly uniform rate in section S1 - N1 (Fig. 12). Also of interest in this section is the onlap of the basal shale member against a component of the ancestral Sweetgrass Arch south of Township 3 (Alberta). Section S2 - N2 (Fig. 13) illustrates that the Swift is much thicker and more uniform in the eastern part of the area. Minor channelling is demonstrated in Townships 2 to 5, where the formation is overlain by basal Gladstone sandstones. The shale member is persistent in this cross-section except in Townships 34N and 35N (Montana); here the ribbon sand is thick and the Rierdon is abnormally eroded, as noted previously. A possible explanation for these observations is that erosion of the Rierdon was intensified over a local paleotopographical high, which may have been emergent during deposition of the Swift shale member, providing a locus for the formation of shallow marine sand bars of the ribbon sand member.

(f) Regional Analysis

Figure 18 (a,b,c) presents the isopach maps of the Swift Formation and its two constituent members. The major features exhibited are:

1. A platform of thick Swift in the southern and eastern parts of the study area, bordered roughly by the 80-foot contour line (Fig. 18c).
2. The north-trending Cut Bank Valley.
3. A north-northwest-trending valley in the centre of the area, here named the Whitlash Valley, after the town of Whitlash, Montana (Twp. 36N, Rge. 4E) (Fig. 2).

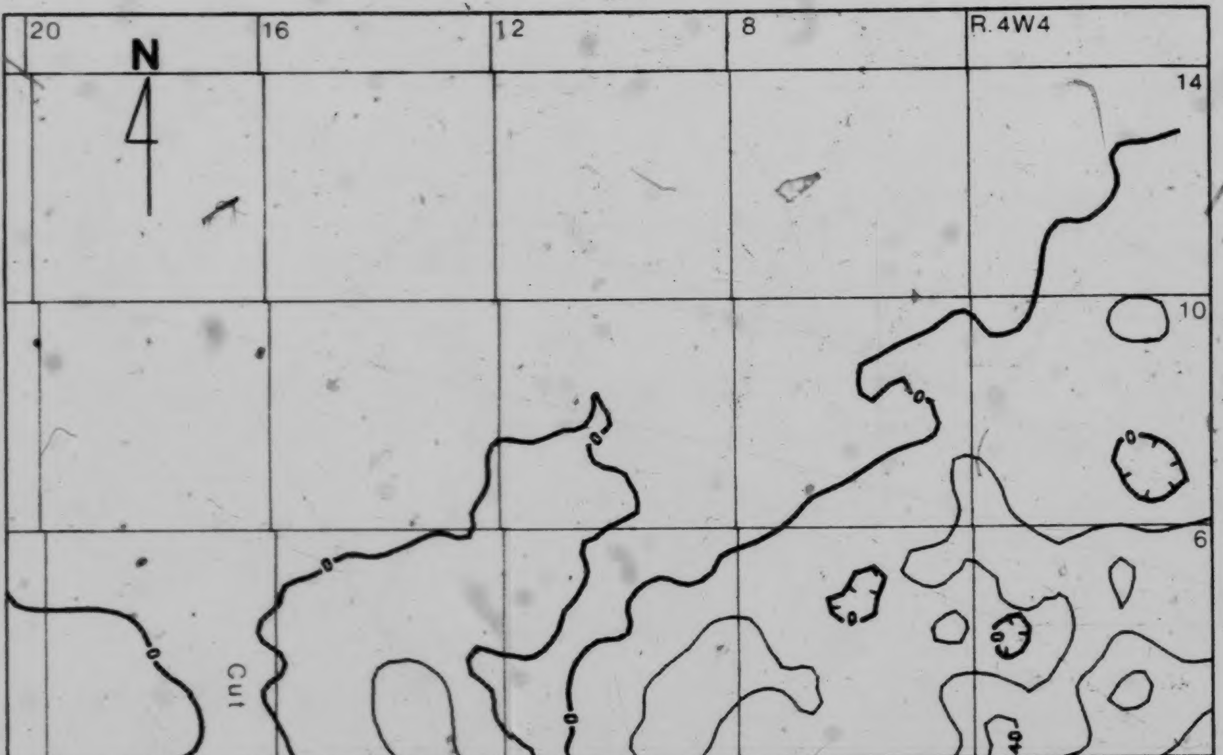
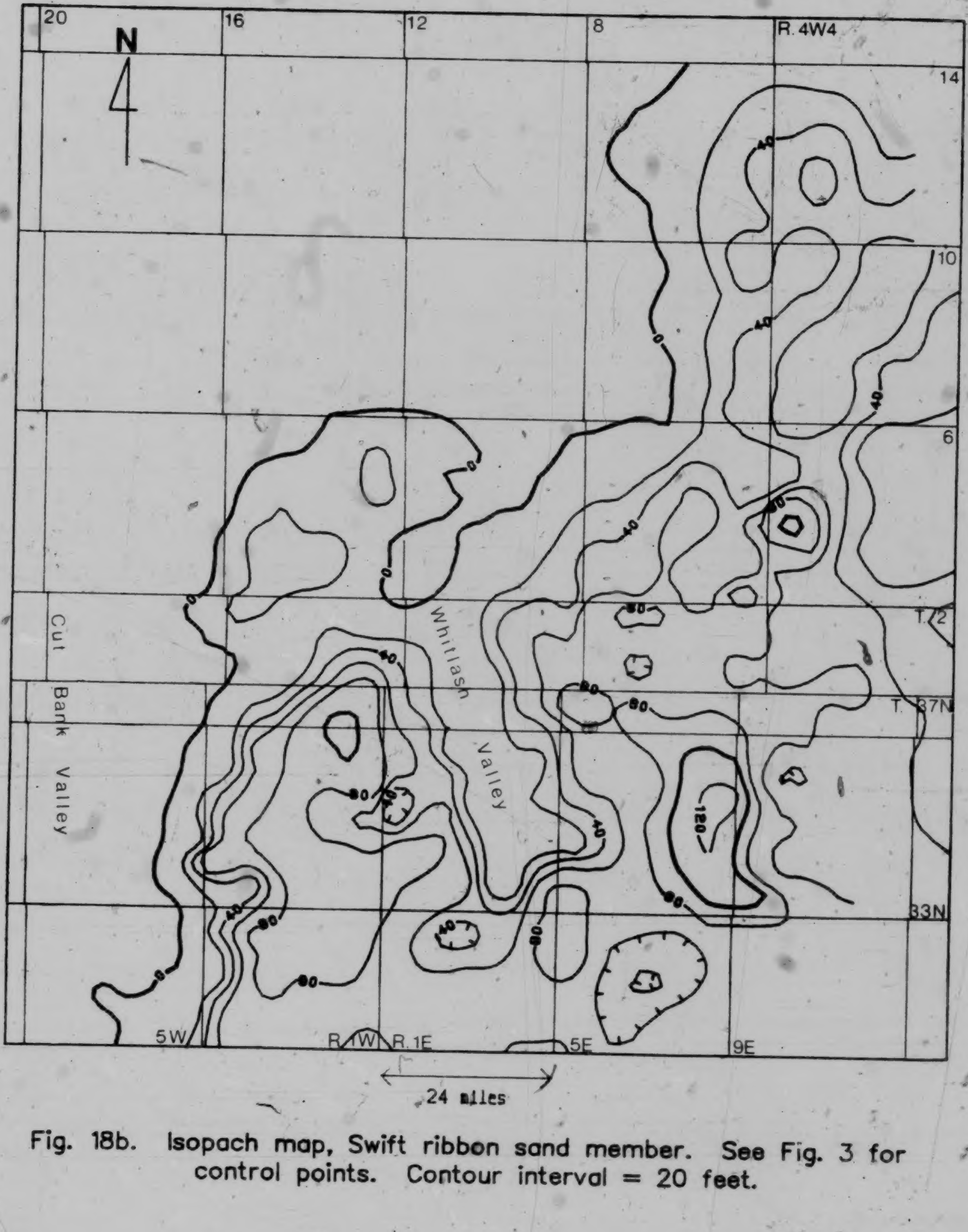

20
16
12
8
R.4W4
N
14
10
6
T. 2
T. 37N
33N
Cut Bank Valley
0
40
80
5W
R.1W
R.1E
5E
9E
24 miles

Fig. 18a. Isopach map, Swift shale member. See Fig. 3 for control points. Contour interval = 20 feet.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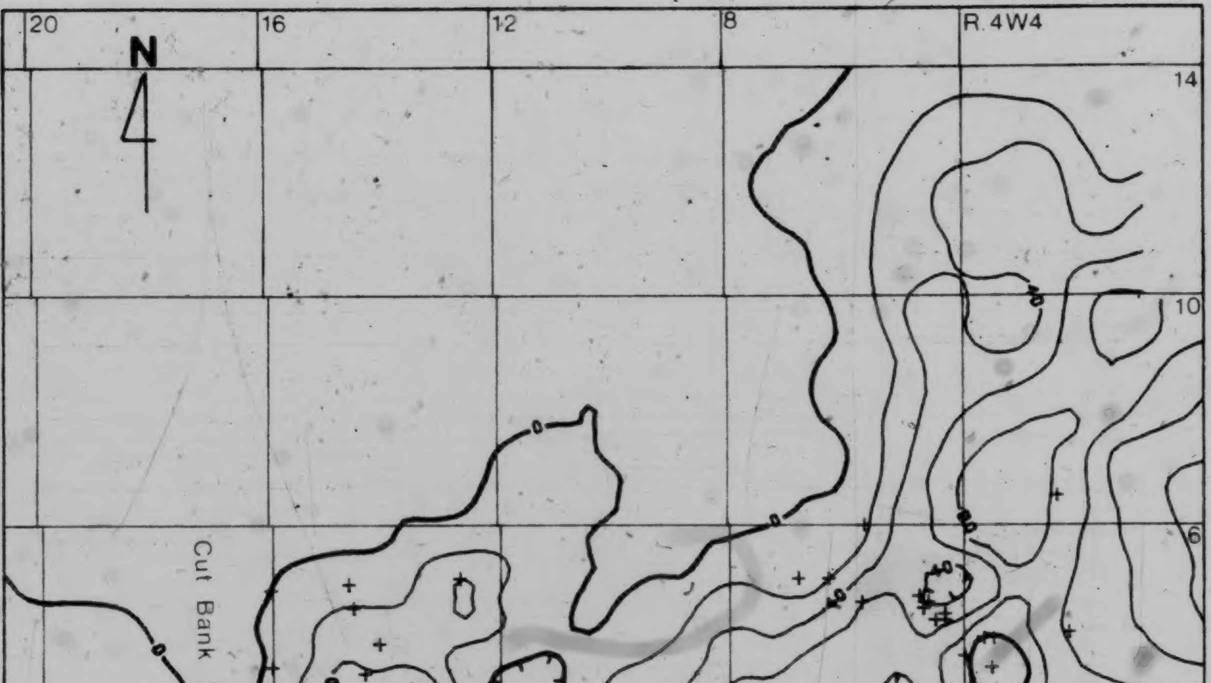
T. 2
T. 37N
33N
Cut Bank Valley
Whitlash Valley
0
40
80
120
5W
R. 1W
R. 1E
5E
9E
24 miles

Fig. 18b. Isopach map, Swift ribbon sand member. See Fig. 3 for control points. Contour interval = 20 feet.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9E
Cut Bank Valley
Whitlash
Valley
tributary
tributary
0
40
80
120
160
24 miles

Fig. 18c. Isopach map, total Swift Formation. Crosses indicate wells with core control; see Fig. 3 for remaining control. Contour interval = 20 feet.

4. The pinchout of the Swift in the north-central part of the area.

Thickening of the basal shale member to the east and west (Fig. 18a) indicates that low topographic relief still existed across the ancestral Sweetgrass Arch at the time of deposition. Generally, however, the Swift was deposited as a widespread shallow marine unit with fairly uniform thickness.

Prolonged erosion, especially widespread minor channelling, between the deposition of the Swift and the Blairmore was responsible for sculpting the present configuration of the Swift. Because of the southward tilt of the area, the formation was eroded to a pinchout well south of the Rierdon erosional edge and consequently, no evidence of a northern paleoshoreline is preserved. The Cut Bank Valley, in the western part of the area, cuts through the entire Swift and into the underlying Rierdon; on the other hand, the Whitlash Valley, in the centre of the study area, does not cut as deeply, and so thins or removes only the Swift along most of its length. Two tributary valleys, shown as trends of thinned ribbon sand, feed into the main Whitlash Valley from the southwest (Fig. 18c). The true configuration of the Whitlash Valley is more intricate, as demonstrated by Branch (1976) in the Fred and George Creek field (Twp. 37N, Rge. 2E (Montana); Fig. 33), but the few wells examined serve to outline only the main trend. North of Township 2 (Alberta), the valley trend swings to the northeast, where it has completely eroded both members of the Swift. Some erosion of the Rierdon appears to have taken place to the northeast along this trend in Township 4, Range 10W4 (Fig. 16), but the valley can be traced no farther than this.

In the east-central part of the study area (Townships 1-10, Ranges 1-3 W4 (Alberta)), the Swift is markedly thinned and is directly overlain by the Beaver Mines Formation. This area experienced extensive erosion during the Early Cretaceous, as discussed in more detail in the Gladstone section of this chapter.

C. Morrison Formation

The Morrison Formation (Fig. 22) is not mapped in this thesis, but it is discussed briefly below, as many previous workers have mapped it in the study area.

Type Section

The Morrison Formation was first defined and described by Eldridge (1896), who designated a type section in eastern Colorado, about 1200 km. southeast of the present study area. Waldschmidt and Leroy (1944) described the formation in more detail from a revised type section nearby, which offered better access and exposure. They distinguished six informal lithologic units totalling 277 feet thick, consisting of variegated shales and siltstones with abundant sandstone beds and a few limestone beds, all of continental origin.

Correlation and Extension to Study Area

The Morrison has been recognized and mapped over a large area of western North America extending as far north as southeastern Alberta and southern Saskatchewan (Peterson, 1966, 1972; Francis, 1957). It is distinguished primarily as a lithostratigraphic unit of continental origin conformably or disconformably overlying marine strata of the Swift and its equivalents, and lying unconformably beneath coarse sandstones or conglomerates of Early Cretaceous age. Facies trends cannot be traced regionally, although informal members are recognized in several areas (Imlay, 1952a; Peterson, 1972).

Well-documented occurrences of undisturbed Morrison nearest to the study area are around Great Falls, approximately 100 km. to the south. Harris (1966) and Walker (1974) used lithological and paleontological evidence to correlate strata cropping out in the Great Falls - Lewistown coal field and along the Missouri River with the Morrison of Wyoming and Colorado. West of the study area, in the disturbed belt of northwestern Montana, Stebinger (1918) and Ross (1959) were unable to recognize the Morrison, although they realized that rocks of this age might be included in strata mapped as the Lower Cretaceous Kootenai Formation. Palynological analysis would have aided them; despite disagreement regarding the true age of Morrison and equivalent strata, their microfloral assemblages are distinct from those of the overlying

Blairmore - Kootenai unit (Brown, 1946; Bell, 1956; Pocock, 1962, 1964). Cobban (1945) tentatively assigned a Morrison age to strata overlying the type Swift, but provided no evidence for this assignment; as previously noted, three samples taken by the author in this interval yielded palynomorphs of Aptian age. In the area immediately north of the Swift type locality, Weimer (1955) showed that the Kootenai overlies the Ellis directly, implying the absence of the Morrison. Mudge (1972) mapped a 200- to 550-foot thick section of Morrison in the Sun River area in the disturbed belt 70 km. southwest of the study area. He found that the formation in the eastern half of his area closely resembled the type Morrison, and graded conformably up from the underlying Swift. In the Foothills and Front Ranges of southwestern Alberta, strata of the correlative Kootenay Group have been mapped and described by several workers, including Norris (1959), Jansa (1972), and Gibson (1977, 1979).

In the present study area, the Morrison has been correlated using geophysical logs in several oil fields (Billings Geol. Soc., 1958). Determinations made by a number of workers are similar, each showing a section of shales and siltstones lying between Swift ribbon sand below and well-developed Lower Cretaceous sandstones above. None of the correlations are documented by lithological or paleontological data, however, and all are shown rather incidentally on sections which are designed primarily to demonstrate characteristics of other (petroleum-bearing) formations. Correlative strata in other nearby fields have been mapped as Kootenai formation (Billings Geol. Soc., 1958; Branch, 1976), and Imlay (1952a) noted the absence of the Morrison in the Sweetgrass Hills, and locally near the Sweetgrass Arch in northwestern Montana. ~~The~~ present author could not recognize any Morrison strata above the Swift, although the paucity of core from Montana hindered this effort.

The Morrison Formation was therefore not mapped in the study area. If it was originally deposited, most of it would have been removed by pre-Blairmore erosion in the Cut Bank and Whitlash Valleys and over the ancestral Sweetgrass Arch. Quite possibly, some Morrison does exist in the eastern part of the study area, but its recognition will depend on finding unambiguous paleontological or lithological evidence and correlating in detail from outcrop sections.

D. Blairmore Group

Leach (1914) first used the name "Blairmore" on a map legend to designate a section of Lower Cretaceous strata in a map area near Blairmore, Alberta (Fig. 1). Rose (1916) described the Blairmore formation and included in it a basal sandstone and conglomerate member that Leach had previously assigned to the underlying Kootenay formation. Formal stratigraphic status was given to the Blairmore Group in

1967, when Mellon named and designated type sections for three constituent formations: the Gladstone (oldest), Beaver Mines, and Mill Creek (youngest). McLean (1977) proposed that the basal sandstone and conglomerate member of the Gladstone be called the Cadomin Formation in accordance with common usage in the central Alberta Foothills, and that the Gladstone be redefined to include only the strata between the Cadomin and Beaver Mines.

Lower Cretaceous Nomenclature Problems

Three important stratigraphic schemes have been used for Lower Cretaceous non-marine strata of the study area. In Montana, the term "Kootenai formation" has been used since 1907. In Alberta, early workers correlated drilling samples from exploratory wells with the Blairmore formation, and so the term "Plains Blairmore" was commonly used in the petroleum industry. Since the work of Glaister (1959) was published, these basal Cretaceous strata have generally been referred to as the Mannville Group, consisting of the informal lower and upper Mannville formations.

To resolve the problems of stratigraphic nomenclature and to choose the most applicable names for use in this thesis, the author studied the origin and nature of each of the Kootenai, Mannville, and Blairmore units. Factors considered were the formal stratigraphic standing of the units and the similarity of their lithological composition to that of the basal Cretaceous of the study area.

The Kootenai formation originated as a miscorrelation with the older Kootenay Formation (now Kootenay Group) of Canada, but the spelling was changed by Fisher (1907) to be in accord with the spelling of the name of the Kootenai Indian tribe of Montana. This minor spelling difference is very confusing, especially as the names apply to completely different lithostratigraphic units. No formal type section has even been proposed for the Kootenai and thus it has no formal stratigraphic standing. Walker (1974, pp. 16-17) discussed some of these problems, and stated:

> "It is highly unfortunate that ... a formal change in nomenclature was not proposed, and the misnomer 'Kootenai' stricken from use as a stratigraphic term in Montana. Blairmore Formation, or perhaps Great Falls Formation ... would have been much more appropriate terms"

Nauss (1945) originally defined the Mannville Formation in central Alberta, and divided it into six members, noting that the overall lithology differed significantly from that of the Lower Cretaceous in the southern Plains of Alberta. Badgley (1952) elevated the Mannville to group status and correlated it throughout central Alberta. The Mannville Group was extended into southern Alberta by Glaister (1959), who suggested that the lower Mannville and upper Mannville be given formation status, although he did not do this himself. Glaister recognized that the lithology of the type Mannville could be compared with his Mannville of southern

Alberta only in a very general way, and that the "Mannville" of the southern Plains could be correlated more closely with the lower two-thirds of the Blairmore of the Foothills.

The historical development of the Blairmore Group as a formal lithostratigraphic unit has been summarized at the beginning of this section and in Chapter II. The lithological and paleontological similarity of the basal Cretaceous strata of the study area to the type Blairmore has been recognized by this author and by several other workers (eg. McLearn, 1945; Glaister, 1959; Mellon, 1967; Walker, 1974; Rice and Cobban, 1977).

Lower Cretaceous, primarily non-marine strata of the study area are therefore assigned to the Blairmore Group, a formal lithostratigraphic unit very similar both lithologically and paleontologically to the correlative strata of the study area. The revised Gladstone and Beaver Mines Formations are also extended to the study area, although the terms "lower Blairmore" and "middle Blairmore" are more commonly used than the proper formation names. The informal Cut Bank member of Montana is raised to formation status and is designated as the Plains equivalent of the Cadomin Conglomerate of the Foothills.

Cut Bank Formation

(a) Type Section and Description

The Cut Bank Formation, named after the town of Cut Bank, Montana (Twp. 33N, Rge. 6W), is the oldest mappable lithostratigraphic subdivision of the Blairmore Group in the study area. It includes strata previously assigned to the informal Cut Bank member of the Kootenai formation, the Vanalta and Cosmos sands of the Border - Red Coulee oil field, and the Taber sandstone of Alberta. The Cut Bank lies completely in the subsurface, hence its recognition depends entirely on cored sections, drilling samples, and geophysical logs.

The type section, described in detail in Appendix A (p. 250), is designated to be the cored interval from the depth of 2753 feet to 2806 feet in the Decalta Altair Milk River (2-4-1-17W4 (Alberta)) well. It is logged in the interval 2755 to 2808 feet on the induction electrical log because of a small miscorrelation of the core depths.

The Cut Bank Formation is primarily a medium- to coarse-grained, poorly-sorted sandstone, the grains of which are composed almost entirely of quartz and dark-coloured chert (Plate 5a). Relative proportions of quartz and chert are strongly controlled by grain size, the chert being more abundant in coarser beds, so that almost all the pebbles are composed of dark chert where the Cut Bank is conglomeratic (Plates 3b, 4b). In the classification scheme of Chen (1968) (Fig. 4), the Cut Bank sandstones are litharenites and extralitharenites. Plastically-deformed mud clasts occur at various levels throughout the formation, usually in coarser sands near the base of fining-upward sequences (Plate 3a). Minor components include: rock fragments of fine clastic sedimentary rocks and argillites, coal fragments and small lenses, siderite, calcite, and pyrite. Sloss and Feray (1948) also noted tourmaline, zircon, leucoxene, barite, magnetite, kaolinite, and possibly greenalite. No fossils have been recovered from the Cut Bank Formation.

Silica cements are dominant in the Cut Bank Sandstone, while calcite and clay minerals are minor cement components. Quartz overgrowths are most common, but cementation by microstylolitic interpenetration of chert grains has been documented by Sloss and Feray (1948). The sandstones are generally quite friable and very porous, but conglomeratic beds are often more tightly cemented by calcite.

Many cored sections of the Cut Bank are composed entirely of medium to coarse sandstone in massive beds, or exhibit only large-scale planar cross-beds or plane beds (Fig. 7, Plate 2d). In several cases, however, evidence of cut-and-fill is abundant, and smaller fining-upward units, conglomeratic at the base and composed of material occasionally as fine as fine sand to silt with thin mud laminae at the top, are observed. Only rarely are small-scale planar and trough cross-beds exhibited.

The lower contact of the Cut Bank sandstone is invariably sharp and erosional; a basal conglomerate with pebbles up to two centimetres in diameter is usually but not always present (Plates 3b, 4b). The upper contact may be gradational, as the sandstone passes into green siltstones of the Gladstone Formation. Erosion prior to the deposition of the Gladstone, however, has produced a sharp upper contact with mudstone, siltstone, or sandstone in some areas.

The Cut Bank Formation is correlated with the Cadomin Formation of the central and southern Alberta Foothills. The stratigraphic position of the two formations is identical, and their mineralogical compositions are very similar (McLean, 1977; Schultheis and Mountjoy, 1978). Cobban (1955), Gallagher (1957), Shelton (1967), and Rice and Cobban (1977) all recognized the passage of the Cut Bank sandstone into a conglomerate identical to the Cadomin to the west in Montana. The Cadomin - Cut Bank correlation will be discussed further in Chapters VI and VII.

(b) Environment of Deposition

Several characteristics of the Cut Bank Formation indicate deposition in a fluvial environment:

1. The formation is confined to a roughly linear valley cut sharply into underlying strata.
2. There is abundant evidence of cut-and-fill, indicative of the lateral migration of the depositing stream(s).
3. No marine fossils were recovered, and the formation

often grades upward into the unquestionably continental Gladstone.

A more specific analysis of depositional environments would require more detailed analysis of long cored sections.

(c) Log Character

Uniform and easily-correlated log responses result from the lithological homogeneity of the Cut Bank Sandstone. The spontaneous potential curve shows a consistent, very marked negative (leftward) deflection because of the uniformly high porosity of most of the sandstone. A steady low gamma ray count is produced by the low clay content and siliceous composition of the formation. Generally uniform moderate acoustic velocities are shown by the sonic log, while the resistivity log is more variable, being controlled largely by the fluid content of the pore spaces.

Thin conglomerate beds are often more heavily cemented than the rest of the formation, and hence are characterized by higher spontaneous potential values and higher acoustic velocities. Beds containing abundant mud clasts show higher spontaneous potential, higher gamma, and lower acoustic velocity values.

(d) Correlation and Regional Analysis

The Cut Bank Formation is encountered only in the western parts of stratigraphic cross-sections W1 - E1 (Fig. 9), W2 - E2 (Fig. 10), and W3 - E3 (Fig. 11). In the western four wells of W1 - E1 and W2 - E2 and the western three wells of W3 - E3, it makes up the lowest part of the

Blairmore Group in the Cut Bank Valley; the isopach map (Fig. 19) shows that it is confined completely to the valley. The western edge of the valley is not distinct, but the eastern edge is much sharper (Figs. 9, 10, 11, 18, 19), and can be traced from the southern edge of the map area as far north as the Jurassic pinchout (about Townships 12 to 13 (Alberta)). This eastern edge cannot be observed north of this point, as the amount of erosion of Mississippian strata has not been studied in this thesis. A similar feature called the Fox Creek Escarpment, which limits the eastern distribution of the Cadomin Formation in west-central Alberta, was outlined by McLean (1976).

West- to northwest-trending tributary valleys breach the eastern edge of the Cut Bank Valley in several places, an excellent example being the valley in which the Chin Coulee oil field is located (Twps. 7 and 8, Rges. 14 and 15W4; Fig. 33) (Oyibo, 1972). More detailed control and contouring of the isopach maps would show Chin Coulee and other small tributary valleys, which are also filled with sandstones of the Cut Bank Formation.

Sandstones similar to the Cut Bank may have been deposited in other valley systems nearby at about the same time, but it is almost impossible to correlate them with the Cut Bank if they cannot be traced continuously from the main Cut Bank Valley. Such sandstones are more reasonably included in the lithologically heterogeneous Gladstone Formation.

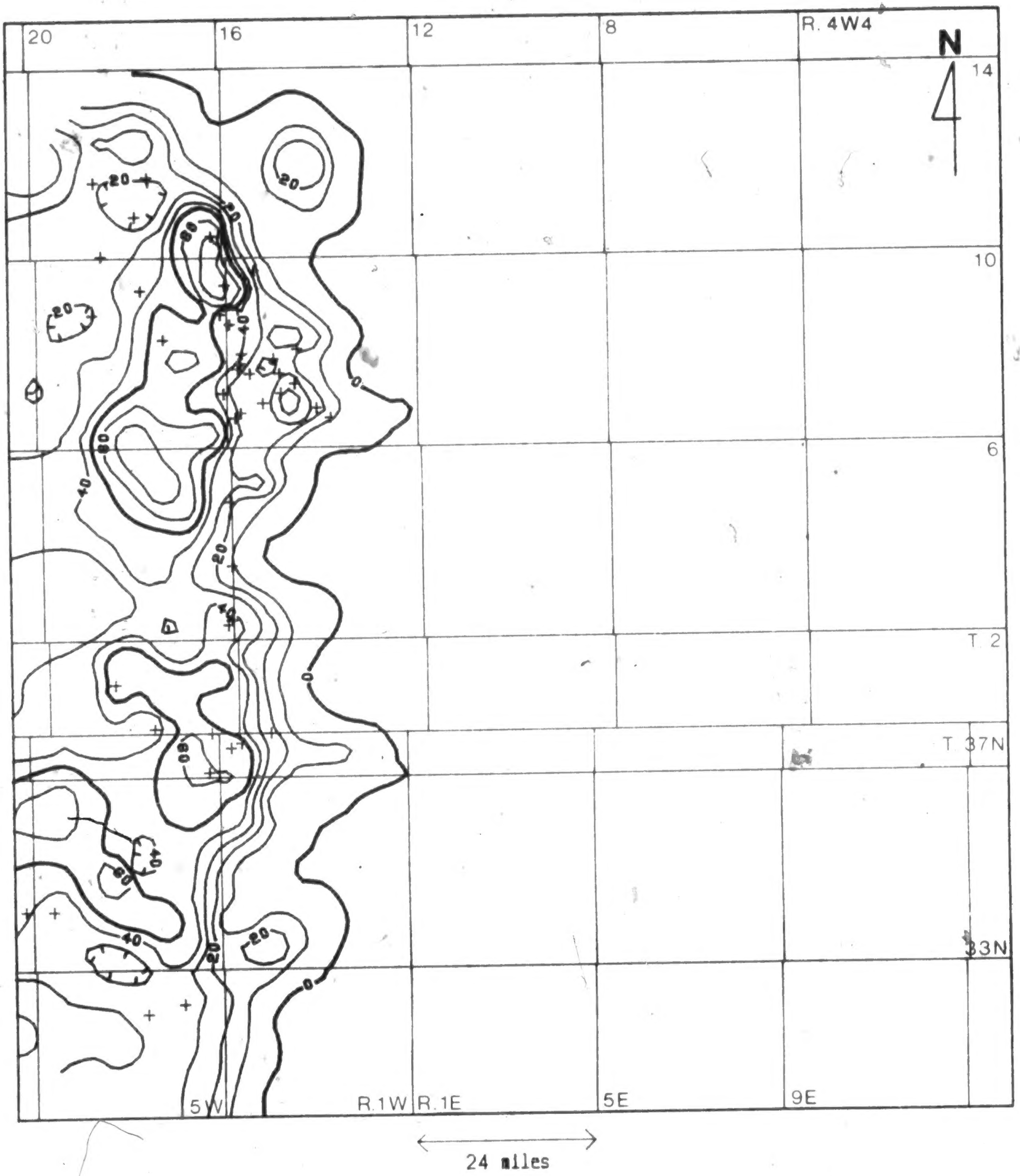
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Fig. 19. Isopach map, Cut Bank Formation. Crosses indicate wells with core control; see Fig. 3 for remaining control. Contour interval = 10 feet.

The thickness of the Cut Bank is controlled primarily by the configuration of the erosional surface upon which it lies. The deepest part of the Cut Bank Valley lies a few miles west of the eastern escarpment, and is outlined by a north-south trend of Cut Bank sandstone generally thicker than 50 feet. Shelton (1967) noted the presence of several north-south trending belts of thick sandstone in the Cut Bank field (Fig. 33), but such belts are not evident on the isopach map by Blixt (1941), and were not noted by the present author. Some of the thickness variations that are observed can be ascribed to facies changes, because at any place where finer facies are present near the top of the formation, they may be included in the Gladstone.

The relationship of the Cut Bank Sandstone and the upper sandy member of the Swift Formation has been debated in print since 1941, when Blixt published the first comprehensive study of the Cut Bank oil field (Fig. 33). He proposed that the Swift and Cut Bank are different facies of one time-stratigraphic unit, with the following reasons:

1. The Cut Bank Sandstone and ribbon sand member occupy the same stratigraphic interval and have similar thicknesses.
2. The units interfinger in several wells near the Cut Bank field.
3. The ribbon sand is not transitional with the underlying Ellis shale.

Erdmann and Schwabrow (1941) agreed with Blixt's reasoning, adding that the ribbon sand and Cut Bank interfinger in wells near the Border - Red Coulee fields as well. Lack of paleontological data led these workers to believe that the Cut Bank and Swift were both Cretaceous because of the similarity of the Cut Bank and the Blairmore conglomerate of the Alberta Foothills. Weimer (1959) knew that the ribbon sand was of Jurassic age on the basis of fossil evidence, and was therefore forced to assign the Cut Bank, which he interpreted to be a nearshore sandy equivalent of the marine ribbon sand, to the Jurassic as well. He also observed the Cut Bank and Swift to interfinger in a section at Badger Creek, west of the present study area, although he has more recently expressed some doubt regarding the validity of this observation (Weimer, pers. communication).

The following observations refute the arguments presented in the previous paragraph:

1. The Cut Bank - Swift boundary is sharp and erosional; the "interfingering" described by several workers can be ascribed to the observation of coarse marine bar sands in the Swift which lithologically are very similar to the Cut Bank.
2. The depositional model proposed for the Swift does not require that the ribbon sand grade upward from the Swift shale.
3. The Cut Bank was deposited in a fluvial environment and not as a beach or as shallow marine sand bars equivalent to the fully marine Swift.

The Cut Bank Sandstone is thus younger and unconformably overlies the Swift Formation. Most recent workers, including Cobban (1955), Glaister (1959), Oakes (1966), Mellon (1967), Shelton (1967), Walker (1974), and Rice and Cobban (1977), have recognized the stratigraphic separation of the Swift and Cut Bank, but none have specifically refuted the arguments for correlation with the Swift ribbon sand.

The precise age relationships of the Cut Bank Valley and the Cut Bank Formation are difficult to interpret, largely because of the great length of time available (about 35 million years - Fig. 21). A major eustatic sea level drop, which occurred in the early Neocomian (Vail et al., 1977), may have reduced base level sufficiently to promote deep incisement and valley formation. Alternatively, more local tectonic movements and consequent availability of sediment may have been the most important factors; in this case, it would not be possible to determine the precise age of valley formation or the possible existence of multiple valley-cutting events (see discussion of Whitlash Valley in Gladstone section below). In either case, there is no clear indication over what time interval during the Early Cretaceous the Cut Bank Formation accumulated.

Gladstone Formation

(a) Type Section and Description

Mellon (1967) designated the type locality of the Gladstone to be along Gladstone Creek in Township 5, Range 2

W5 Meridian (Fig. 1). Here the formation is 250 feet thick and consists of three informal members:

1. A basal, medium- to coarse-grained siliceous sandstone and conglomerate, 43 feet thick.
2. Dark grey, green, and red shale interbedded with calcareous siltstone and fine-grained sandstone, 172 feet thick.
3. Interbedded dark grey calcareous shale and silty limestone with abundant freshwater invertebrates, 35 feet thick.

The present author has accepted McLean's (1977) suggested revision of the Gladstone which excludes the basal sandstone, and therefore, the Gladstone as mapped in this thesis comprises only the upper two members.

Heterogeneous lithologies distinguish the medial member. Mellon (1967) did not discuss this member in detail, but his descriptions at other localities show that it is correlated on the basis of stratigraphic position and general character rather than by matching specific beds or horizons.

The upper member of Mellon's Gladstone is the "Calcareous" member described by Glaister (1959). At the type section, Mellon distinguished three distinct limestone units separated by shaly intervals, but Mellon's and Glaister's descriptions of other sections make it clear that the "Calcareous" member can be correlated only by its general lithology of dark calcareous shales, thin limestones, and calcareous siltstones and sandstones, rather than by specific markers or sequences.

(b) Lithology and Fossil Content

A wide variety of lithologies are exhibited throughout the study area by the Gladstone Formation. Volumetrically dominant are variegated, poorly-sorted mudstones, silty mudstones, and siltstones, which are coloured maroon, grey-green, light to dark grey, and occasionally yellow to brown. Thick monotonous sequences of mottled maroon and greenish mudstones and silty mudstones are particularly common, containing only a few beds with some irregular carbonate nodules. Grey and green-grey fine-grained sediments are often characterized by abundant small (1 mm.) siderite nodules. Organic remains are rare, although plant fragments can be found in the medium to dark grey rocks.

Sandstones are abundant and are very similar to those of the Cut Bank, being composed primarily of quartz and chert (Plate 5b). Gladstone sandstones are generally finer and more quartzose than Cut Bank sandstones, although some beds at the base of the Gladstone are nearly identical to the Cut Bank (Plate 3c). In an area surrounding the Grand Forks oil field (Twps. 11-13, Rges. 12-14 W4 (Alberta)), Gladstone sandstones are very quartzose, even where medium-grained (Plate 6a). Most Gladstone sandstones fall into the sublitharenite to litharenite categories of Chen's (1968) classification, with only rare extralitharenites or quartzarenites. Minor components include siderite nodules, detrital carbonate grains, weathered feldspars of various types, and carbonaceous organic debris, occasionally in the form of coaly fragments or partings. Silica is the primary cement, although not as dominant as in the Cut Bank, while clay, particularly kaolinite, and calcite are other important cementing agents. The proportion of cement is extremely variable, so that the degree of induration and amount of porosity varies widely.

Sandstone sequences of the Gladstone generally fine upward, and sometimes exhibit large-scale planar cross-bedding and plane bedding, and more rarely smaller trough and planar cross-beds (Fig. 7). Examples of cut-and-fill and of intervals possessing abundant mud clasts can be found, but are rarer than in the Cut Bank. Gladstone sandstone beds are rarely thicker than 20 feet; each usually lies on a sharp basal contact and grades into siltstones toward the top. Sandstone bodies are lenticular and cannot be correlated except over small areas with closely-spaced well control, such as in the Fred and George Creek field in northern Montana (Branch, 1976) (Fig. 33).

In the western part of the study area, the "Calcareous" member is recognized. Black calcareous shales and beds of micritic tan argillaceous limestone no more than a few feet thick are most characteristic of the "Calcareous" member, but abundant calcareous siltstones and lithic sandstones also exist. These coarser beds are very similar to siltstones and sandstones in the lower part of the

Gladstone, and consequently can be recognized with confidence only where they overlie the more distinctive limestone and shale beds. As noted in part (a), the "Calcareous" member is distinguished on general lithology only, as there are no distinctive marker beds to use for correlation. Formation top determinations made by different workers vary widely, because most correlations depend heavily on geophysical log data, which are almost always insufficient to distinguish the "Calcareous" member from the rest of the Gladstone.

The contacts of the Gladstone Formation with the surrounding formations vary in character. East of the Cut Bank Valley, the base of the Gladstone represents the major Jurassic - Cretaceous unconformity, and so the contact is very sharp, especially where a basal Gladstone sandstone is developed (Plate _c). Where a basal Gladstone sandstone lies over a coarse bar sand of the Swift Formation, it is nearly impossible to distinguish the two on geophysical logs, although they usually can be separated in core. West of the eastern margin of the Cut Bank Valley, where the Gladstone overlies the Cut Bank Sandstone, the contact is gradational or at least conformable. The upper contact of the Gladstone generally marked by feldspathic sandstones of the Beaver Mines Formation sharply overlying finer-grained lithologies of the Gladstone.

Fossils are rare in the Gladstone below the "Calcareous" member. Megafloral and microfloral fossil assemblages composed entirely of terrestrial plant remains have been described from both the Gladstone and Beaver Mines (see Chapter V), but most have actually been recovered from the Beaver Mines. More than 50% of the Gladstone samples processed for palynological analysis for this thesis failed to yield any identifiable floral remains, although in several cores, grey-coloured intervals bear abundant root traces (Plate 3d).

A much more complete suite of fossils is present in the "Calcareous" member. Fresh-water invertebrates, including pelecypods, gastropods, and ostracods are locally so abundant that some thin beds can almost be considered to be coquinas. The palynomorph assemblage is more diverse than that in the underlying part of the Gladstone, and is characterized by taxa indicating a fresh- to brackish-water environment (S.A.J. Pocock, C. Singh, pers. communication). Loranger (1951) described an identical microfossil zone in the Blairmore of central and southern Alberta and called it the Metacypris persulcata zone after a characteristic ostracod. Mellon and Wall (1963) disputed Loranger's identification of M. persulcata and other ostracods, and Mellon (1967) referred to the fauna as the Protelliptio hamili fauna, after the dominant pelecypod. More commonly, the term "ostracod zone" is used to signify the informal biostratigraphic zone, which is not synonymous with the lithostratigraphic "Calcareous" member. The two are largely coincident because of facies control, but almost all the fossil taxa are sufficiently long-ranging to be found at other stratigraphic levels (Mellon, 1967).

(c) Environment of Deposition

The Gladstone Formation below the "Calcareous" member was deposited in non-marine, dominantly fluvial environments, as indicated by its lithological heterogeneity, sedimentological features (as discussed in the following paragraphs), abundance of reddish beds, and terrestrial floras and faunas (Bell, 1956; Pocock, 1962; Mellon and Wall, 1963).

Sandstones in the Gladstone were deposited in fluvial channels, forming lenticular bodies surrounded by continental finer-grained sediments. The bulk of the formation was deposited over floodplains, as indicated by the presence of root traces, siderite and other carbonate nodules, and plant remains (Collinson, 1978). Red-coloured mudstones and siltstones stained by oxidized iron indicate only periodic wetting, which occurs in arid areas with a low water table, while grey-coloured beds with root traces and siderite nodules were deposited under more reducing conditions associated with a high water table (Collinson, 1978). The preponderance of red beds in the Gladstone suggests an arid environment with only limited low areas of backswamp deposition.

Much wetter environmental conditions are represented by strata of the "Calcareous" member. Its fossil assemblage has been interpreted to denote fresh or fresh to brackish water by various workers (Loranger, 1951; Glaister, 1959; Mellon and Wall, 1963; S.A.J. Pocock, pers. communication; C. Singh, pers. communication). A lacustrine model of deposition accounts well for the abundance of dark calcareous shales and thin carbonates (Reineck and Singh, 1973). Although little core of the coarser strata of the "Calcareous" member has been observed, it may be postulated that these strata were laid down along shorelines or in lacustrine deltaic and bar complexes. Oakes (1966) discussed such a lacustrine depositional model for the "Calcareous" member (which he called the Moulton member (Table 3)) in the North Cut Bank field (Twp. 37N, Rge. 4W (Montana)). His model, although based on only a small area, can probably be applied to the "Calcareous" member over most of its range in the thesis area.

(d) Log Character

Below the "Calcareous" member, the heterogeneity of lithological sequences in the Gladstone Formation precludes the development of log features correlatable over the study area, but does serve to distinguish the Gladstone from the more uniform Upper Jurassic formations. The overlying Beaver Mines Formation is equally heterogeneous, however, and the two can be separated with confidence only where a basal Beaver Mines sandstone can be recognized.

The "Calcareous" member is more distinctive where well-developed. A sharp log "kick" of high resistivity and acoustic velocity and low gamma emission marks the argillaceous limestone, as demonstrated at 3580 feet in the Bow Valley Tempest (10-30-9-19W4) well on stratigraphic cross-section W1 - E1 (Fig. 9). Low resistivity and acoustic velocity values, high gamma counts, and positive spontaneous potential deflections denote the dark shales. Sandstone and siltstone bodies in the member do not provide unique log signatures because of their irregular distribution, and therefore, unless the distinctive limestone response is found, it is almost impossible to distinguish the "Calcareous" member solely on log character.

(e) Correlation

Correlation of the Gladstone is made difficult not only because of the lack of distinctive log responses, but because it was deposited on an erosional surface with considerable local relief and was later subjected to variable erosion before being covered by the Beaver Mines Formation. Despite these problems, examination of the stratigraphic cross-sections and isopach map provides some insight into patterns and control of deposition.

In cross-section W1 - E1 (Fig. 9), the Gladstone is present in the 10-30-9-19W4 (Alberta) well, although it is quite thin. A thin sequence of fine-grained sediments associated with the deposition of the Cut Bank Formation makes up the lower Gladstone, whereas the "Calcareous" member is fully developed. The lower Gladstone pinches out just east of the next well on the section, but the "Calcareous" member can be traced to the edge of the Cut

Bank Valley in 4-27-10-16W4. The existence of Gladstone strata in 4-16-10-9W4, 11-24-9-8W4, and 4-9-10-6W4 is problematical, but in the eastern three wells, the abruptly-increased thickness of Jurassic strata signifies the presence of an erosional escarpment facing west, on top of which little or no Gladstone strata were deposited.

In cross-section W2 - E2 (Fig. 10), the entire Gladstone is thick in the western four wells above the Cut Bank Sandstone. The difficulty in correlating the "Calcareous" member solely on log data is illustrated east of 4-2-1-16W4; at some point the lacustrine strata of the member grade into floodplain deposits with similar log characteristics, but the precise location is unclear. The formation thins sharply in 7-18-1-12W4 over the Cut Bank - Whitlash interfluve. A distinctive sequence of two thin sandstones with intervening and overlying finer strata, which can be traced several townships to the south, fills the Whitlash Valley in 6-1-1-11W4. To the east, the Gladstone thins and is generally fine-grained, implying that little net deposition took place except in 6-29-1-8W4, where a basal sandstone reflects the presence of a small stream valley.

In the northern two wells of section S1 - N1 (Fig. 12), the Gladstone lies directly on Mississippian beds and pinches out against a north-facing erosional escarpment between 4-20-13-13W4 and 7-30-12-13W4. As far south as 15-17-7-14W4, little or no Gladstone is preserved over the

Jurassic except in local valleys. An example of such a valley is in 5-36-11-14W4, where 50 feet of Gladstone quartzose siltstones can be related to a complex system of lower Blairmore drainage outlined by Berry (1974) in the Grand Forks area. South of 4-32-6-14W4, the Gladstone is well developed, especially from 7-18-1-14W4 to NWNW 16 32N 3W (Montana), where the sequence consists of a medial sandstone surrounded by finer facies.

Section S2 - N2 (Fig. 13) also illustrates the northern escarpment and the presence of a thick section of Gladstone south of Township 4 (Alberta).

(f) Regional Analysis

The Gladstone thins to a zero edge in the eastern part of the study area, but thickens sharply in the extreme north and to the southwest, and along a north - south trend in the centre of the isopach map (Fig. 20). This distribution is best explained by interpreting the study area to have been a broad upland during the time of Gladstone deposition, over which sedimentation took place primarily in major stream valleys such as the Whitlash Valley, which corresponds to the north - south trend where the formation is abnormally thick. Rapid thickening of the Gladstone in the northern part of the thesis area corresponds to the abrupt erosional edge marking the northern margin of the southeastern platform of Jurassic strata. This escarpment extends northerly in the extreme northeastern part of the thesis area, as illustrated on section W1 - E1, and is cut back to

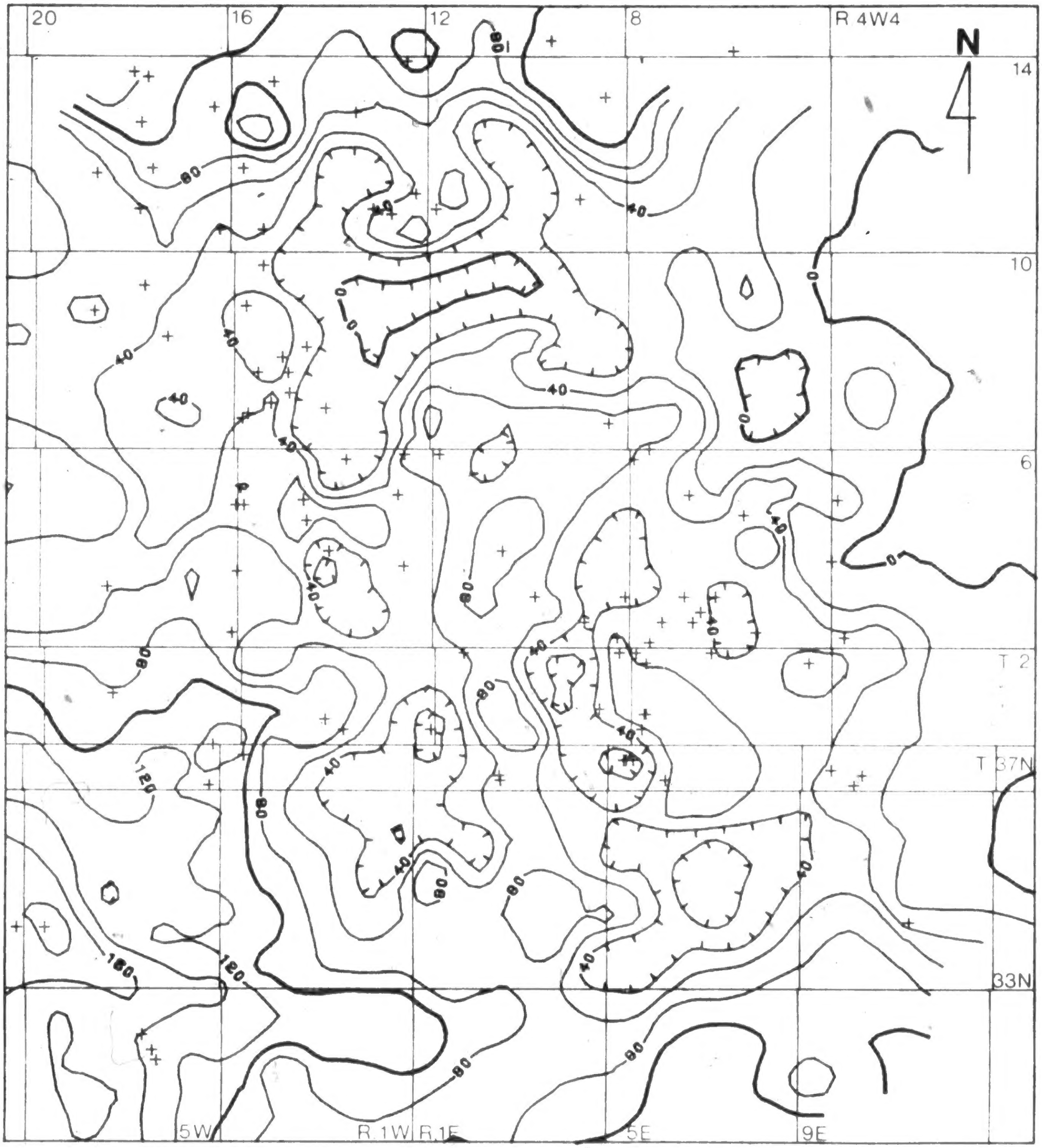

20
16
12
8
R 4W4
N
14
10
6
T 2
T 37N
33N
5W
R 1W
R 1E
5E
9E
0
40
80
120
160
24 miles

Fig. 20. Isopach map, Gladstone Formation. Crosses indicate wells with core control; see Fig. 3 for remaining control. Contour interval = 20 feet.

the south in Ranges 11 to 14W4, where the Grand Forks stream system eroded much of the Jurassic (Berry, 1974).

Strata of the "Calcareous" member are limited to the Cut Bank Valley west of the broad upland, as the lacustrine-associated environments in which they were laid down were probably bounded by the remaining relief on the eastern edge of the Cut Bank Valley. D. James (pers. communication) has found that "Calcareous" member strata increase in thickness and show more evidence of open-water deposition to the north and west.

Christopher (1974) mapped strata equivalent to the Gladstone only in major valleys incised in the broad upland of the Swift Current platform (Fig. 24), which is the eastern continuation of the upland of the present study area. He postulated pre-Blairmore uplift of the Swift Current platform, which caused stream rejuvenation, deposition of valley-fill sediments, and accelerated interfluve erosion.

The Whitlash Valley and associated minor valleys were probably cut in response to the same conditions which caused erosion of the Cut Bank Valley. Christopher's interpretations indicate that local tectonic controls were more important than eustatic sea level changes in valley incisement. Basal sands of the Gladstone may have been deposited simultaneously with the Cut Bank Formation, their finer grain size being attributable to greater distance from the western source area.

(g) Other Stratigraphic Terms

Perhaps the most overworked and least clearly defined stratigraphic unit in the Gladstone Formation is the Sunburst, an informal member used by early workers to refer to a local Lower Cretaceous reservoir sandstone in the Kevin - Sunburst field (Fig. 33) (Hager, 1923; Collier, 1929; Howell, 1929; Romine, 1929). Dobbin and Erdmann (1934) extended the Sunburst to the Cut Bank and Border - Red Coulee fields to the west (Fig. 33), even though they realized the sandstones were not exactly correlative. They also used the term "Sunburst zone" to include associated red and green siltstones and mudstones as well as the Sunburst sand. Since then, the Sunburst has been "recognized" as far north as the Wayne field (Twp. 27, Rge. 20W4 (Alberta)) (Erickson and Crewson, 1959), as far south as Great Falls (Walker, 1974; Burden and Hopkins, 1981), and for substantial distances east and west of the Kevin - Sunburst field.

The term "Sunburst" should be restricted to its original range in the Kevin - Sunburst field. It would be most useful if referred specifically to a type section, although it appears that almost all workers agree on its boundaries in this area.

Most of the other names used for informal lithostratigraphic units of the Gladstone in the study area have been applied to localized sequences, usually sandstone bodies. These names are often useful, as they are normally restricted to rather sharply-defined strata in a single field or group of fields. Some are clearly redundant, and their origin can be attributed to the lack of correlation with previously-defined terms. For example, the "brown lime" of Oakes (1966) in the North Cut Bank Field (Twp. 37N, Rge. 4W (Montana)) is clearly part of the "Calcareous" member. Some names have been used by various workers to refer to completely different strata, and would best be eliminated. A good example is the Moulton sandstone, found in small fields in the Border - Red Coulee - North Cut Bank area, which is composed of quartzose sandstone according to some workers, and andesitic tuffaceous sandstone according to others. Additional names of at least local significance include: the Lander sand (Cut Bank field), various Sunburst and "lower Mannville" subdivisions, and the Manyberries sand (extreme southeastern Alberta).

In summary, the lithological variability of the Gladstone dictates that informally-named lithostratigraphic units should be correlated only over small sharply-defined areas of no more than a few tens of square miles. Only the "Calcareous" member has proved to be sufficiently distinctive to merit correlation over a large part of the study area.

Beaver Mines Formation

The Beaver Mines Formation is discussed briefly here in order to clarify the upper boundary of the Gladstone Formation.

A composite section exposed on Mill and Gladstone Creeks in Township 5, Range 2 W5 (Fig. 1) makes up the type Beaver Mines Formation. Mellon (1967) found this section to be 930 feet thick, although he noted that the thickness varies substantially over a small area near the type locality. He measured a 430-foot-thick lower sandy division sharply overlying the "Calcareous" member of the Gladstone, the basal part of which consists of several feet of dark green-grey shale and siltstone grading up to a 35-foot green, fine-grained, cross-bedded sandstone containing lenses of volcanically-derived pebbles. Two beds composed of green, medium- to coarse-grained, feldspathic sandstone, 40 and 85 feet thick, are also present in this lower division. The intervening and overlying beds consist of dark green-grey shale, siltstone, and fine-grained sandstone. Mellon's upper division of the Beaver Mines, 500 feet thick, is dominated by fine-grained rocks, especially varicoloured mudstones, with a decreasing proportion of sandstone toward the top.

Several cored sections of the basal part of the Beaver Mines were examined in the present study area. Basal sandstones, where present, are quite immature, containing up to 20% matrix, usually composed of bentonitic clays which swell upon contact with water (Plate 6b). Major grain components include 10 - 25% feldspar, abundant volcanic rock fragments, and usually less than 40 - 50% quartz and chert. Minor components include dark- and light-coloured micas, chlorite, detrital carbonate grains, and abundant plant fragments. In Chen's (1968) classification, sandstones of the Beaver Mines Formation range from feldspathic litharenites to extrafellitharenites.

On geophysical logs, Beaver Mines sandstones are difficult to recognize and correlate. High clay and feldspar contents produce high gamma ray counts normally associated with more argillaceous rocks. In addition, the abundant clay matrix fills pore spaces and thus suppresses the negative spontaneous potential deflection which usually typifies sandstones. Sonic and resistivity responses are quite variable, although they can be useful for local correlations.

Cores of the Beaver Mines were not studied sufficiently to permit detailed environmental interpretations. Continued sedimentation under a continental - fluvial depositional regime can be assumed on the basis of the abundance of floodplain-type fine sediments and a fossil assemblage very similar to that of the Gladstone. Lacustrine or marginal marine influence in Beaver Mines strata has been reported (D. James, pers. communication) immediately to the west and northwest of the study area.

The sharp lithological contrast between the more mature, very siliceous Gladstone sandstones and the less mature, feldspathic Beaver Mines sandstones marks the boundary between the two formations. Where the "Calcareous" member is present, there is usually little difficulty in recognizing the contact. Where the Beaver Mines lies directly on the lower Gladstone, however, accurate picks depend upon closely-spaced core control, as the siltstones and mudstones of the two formations are virtually indistinguishable. In such cases, the base of the Beaver Mines was picked at the lowest occurrence of feldspathic argillaceous sandstone beds. Over the paleogeographical upland where the Gladstone is thin or absent, it is sometimes difficult to determine whether the basal Cretaceous sandstone lying over the eroded Jurassic surface belongs to the Gladstone or to the Beaver Mines.

In cases where sandstone bodies are of mixed provenance (see Chapter VII), some arbitrary definition is required to separate Gladstone from Beaver Mines sandstones. It is proposed here that a reasonable cut-off is a 5% feldspar content in sandstones. In the western part of the study area and immediately to the west and northwest, however, in the area currently being investigated by D. James, there exist very quartzose Gladstone-type sandstone bodies above feldspathic Beaver Mines sandstones. It is suggested that these quartzose sandstones be included in the Beaver Mines Formation, because they represent localized short-term deposition of quartzose sand, probably derived from older sediments, in the midst of the Beaver Mines depositional regime.

V. AGE RANGES OF LITHOSTRATIGRAPHIC UNITS

Introductory remarks made in Chapter I indicated that it is very difficult to determine precise ages for Late Jurassic and Early Cretaceous fossil assemblages. Progress is now being made, however, toward resolving differences among interpretations based on different fossil groups from different areas.

Figure 21 summarizes the age ranges of Upper Jurassic and Lower Cretaceous strata in the study area. Because of different paleontological interpretations and the poor quality of assemblages preserved in some strata, most formation boundaries are shown approximately and serve only to indicate the most likely age ranges. Three stratigraphic columns are shown: one for the part of the study area west of the Sweetgrass Arch, one for the part east of the arch, and one for the part north of the Jurassic pinchout (Townships 13-15 (Alberta)). The east and west columns together can be viewed as a west-to-east "cross-section" of the area.

The reader is referred to Chapter VI, Fig. 22, and Table 3 for correlation of stratigraphic units discussed below which are outside of the study area.

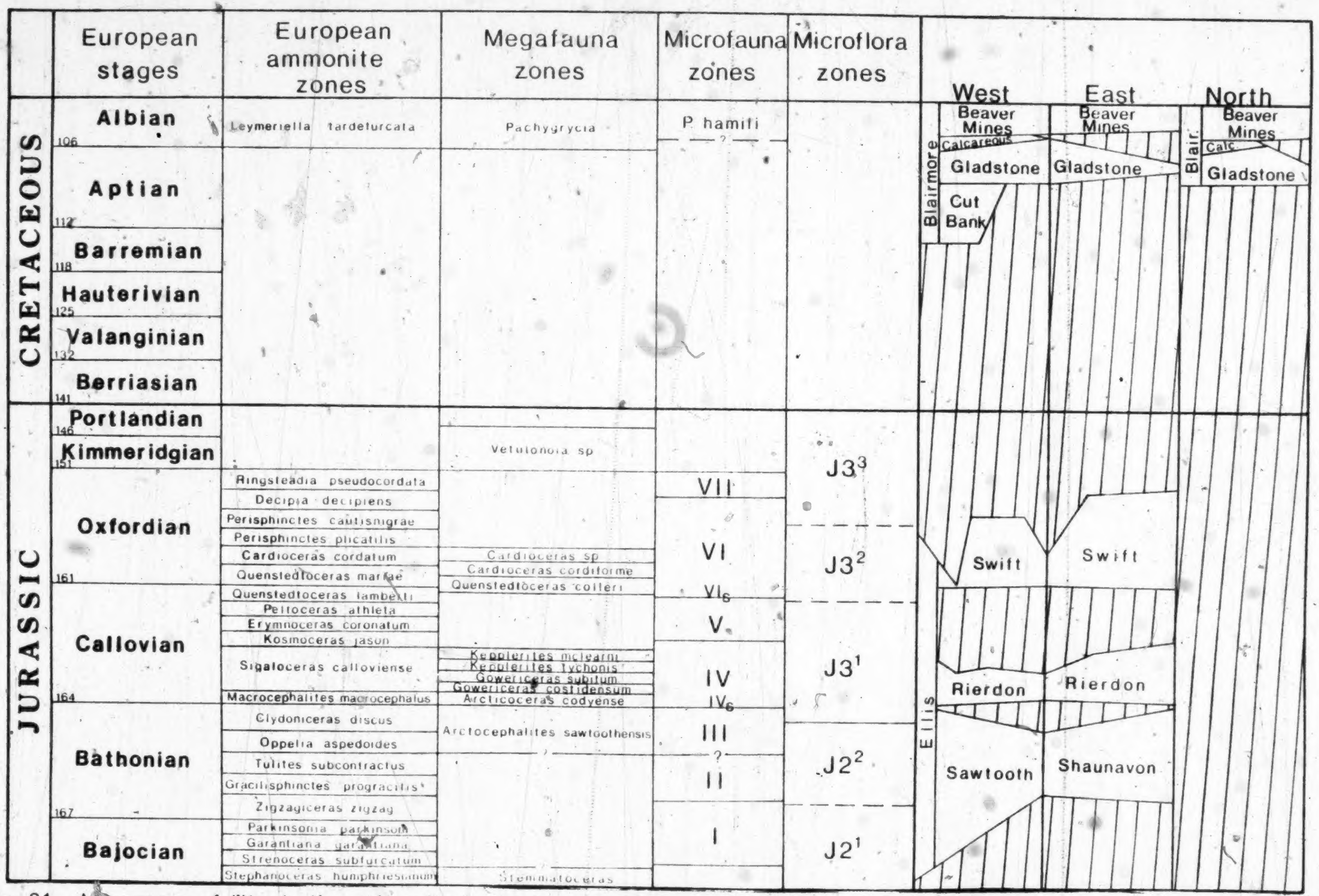

European stages
European ammonite zones
Megafauna zones
Microfauna zones
Microflora zones
West
East
North
CRETACEOUS
JURASSIC
Albian
106
Aptian
112
Barremian
118
Hauterivian
125
Valanginian
132
Berriasian
141
Portlandian
146
Kimmeridgian
151
Oxfordian
161
Callovian
164
Bathonian
167
Bajocian
Leymeriella tardefurcata
Ringsteadia pseudocordata
Decipia decipiens
Perisphinctes cautisnigrae
Perisphinctes plicatilis
Cardioceras cordatum
Quenstedtoceras mariae
Quenstedtoceras lamberti
Peltoceras athleta
Erymnoceras coronatum
Kosmoceras jason
Sigaloceras calloviense
Macrocephalites macrocephalus
Clydoniceras discus
Oppelia aspedoides
Tulites subcontractus
Gracilisphinctes progracilis
Zigzagiceras zigzag
Parkinsonia parkinsoni
Garantiana garantiana
Strenoceras subfurcatum
Stephanoceras humphriesianum
Pachygrycia
Vetulonoia sp
Cardioceras sp
Cardioceras cordiforme
Quenstedtoceras collieri
Kepplerites mclearni
Kepplerites tychonis
Gowericeras subitum
Gowericeras costidensum
Arcticoceras codyense
Arctocephalites sawtoothensis
Stemmatoceras
P. hamifi
?
VII
VI
VI$_6$
V
IV
IV$_6$
III
?
II
I
J3^3
J3^2
J3^1
J2^2
J2^1
Beaver Mines
Calcareous
Gladstone
Cut Bank
Blairmore
Swift
Rierdon
Ellis
Sawtooth
Beaver Mines
Gladstone
Swift
Rierdon
Shaunavon
Beaver Mines
Calc.
Blair.
Gladstone

Fig. 21. Age ranges of lithostratigraphic units in thesis area. European ammonite zones after Arkell (1956) and Imlay (1962); megafauna zones after Imlay (1945, 1962) and Stelck and Kramers (1980); microfauna zones after Brooke and Braun (1972) and Mellon (1967); microflora zones after Pocock (1972). Small numbers refer to geochronologic ages in millions of years, after Van Eysinga (1975). "North" refers to that part of the thesis area north of Township 12 (Alberta); "West" and "East" refer to the western and eastern halves of the remaining area.

A. Jurassic Formations

The dominantly marine strata of the Ellis Group and Shaunavon Formation contain an abundance of fossil megafaunas, microfaunas, and microfloras which can be used for age and paleoenvironmental determinations.

Megafauna

Megafaunal zones described by Imlay (1947, 1952a,c, 1953, 1962) provide the most useful and rigorously-defined dating scheme. Ammonites are the most important index fossils and provide the basis for correlation with the European standard zones, but other molluscs such as bivalves and belemnites are also significant components of the North American zones. To date the formations of the Ellis Group, Imlay collected from the type sections and from numerous exposures on the flanks of Tertiary intrusives in Montana, including the Sweetgrass Hills. Similar age ranges were interpreted by Frebold (1957) for megafaunal assemblages collected from correlative strata in the Fernie Formation of the Alberta Foothills and Front Ranges.

As it is not feasible to make extensive megafaunal collections from subsurface localities, microfossil assemblages must be used as the basis of subsurface correlations.

Microfauna

Microfaunal assemblages of the Upper Jurassic of the western interior United States were described by Loeblich and Tappan (1950a,b), Lalicker (1950), Swain and

Peterson (1951, 1952), and Peterson (1954), as outlined in Chapter II. Wall (1960) described the Jurassic microfaunas of Saskatchewan but deemed them unsuitable for detailed age dating. He found that the foraminifera are generally long ranging and that the ostracods, while better index fossils, are usually less abundant. He correlated ostracod and foraminiferal assemblages with those of the Ellis Group, and dated them solely on the basis of those correlations. Brooke and Braun (1972) constructed a detailed microfaunal zonation scheme for the same strata, which includes seven primary assemblages and three sub-assemblages comprising 51 ostracod species, 108 foraminifera species, and at least three charophyte species. They traced their assemblages across southern Saskatchewan, relating them to the Williston Basin lithostratigraphic nomenclature, and also traced them to two outcrop sections in the Little Rocky Mountains of north-central Montana. Unfortunately, they did not relate the microfaunal assemblages directly to Imlay's megafaunal zones, and hence were unable to provide precise age ranges. Their microfaunal assemblages are sufficiently well defined, however, to be useful in subsurface stratigraphic correlation.

Microflora

Pocock (1962, 1970, 1972) has published most of the recent work on Jurassic microfloras of western North America. He described the composition of seven Jurassic floral zones in his 1972 paper, and defined fairly sharply-bounded age ranges which are significantly younger than those of Imlay's megafaunal zones. The present author regards the megafaunal ages as more reliable than the microfloral ages for the following reasons:

1. Most of the microfloral taxa are relatively long ranging; Pocock assigned age ranges by comparing the percentage of species common to assemblages from the upper Vanguard Formation (now Group) in Saskatchewan (Fig. 22) and assemblages from strata in England.
2. Pocock maintained that the upper Vanguard contains the ostracod "_Metacypris_" _pahasapensis_ which is no older than Kimmeridgian. However, at another point (1962, p. 6), he expressed doubt as to the value of _M. pahasapensis_ as an age indicator. Klingspor (1958) regarded this species as an indicator of a marine environment and did not use it in age determinations, and Christopher (1974) also disputed its value as an index fossil.
3. Pocock correlated the upper Vanguard with the basal part of the Kootenay Formation in the Alberta Foothills (basal part, Morrissey Formation, Kootenay Group of Gibson's (1979) revised nomenclature (Fig. 22)). This correlation is questionable, as the basal Kootenay may be as young as Portlandian (see Chapter VI).

Finally, Pocock (1962) himself, in a discussion of previous work on Jurassic - Cretaceous dating in western Canada, expressed considerable uncertainty regarding exact dating of

Upper Jurassic strata by means of microfloral and microfaunal analysis.

Conclusions

Age ranges of the megafaunal zones defined by Imlay (1947, 1953) are used to date the Jurassic strata of the study area. At the present time, the microfossil assemblages alone are useful only for rough stratigraphic correlation, as they are insufficiently subdivided to document the extent of age variations resulting from onlap and erosion of formations. Studies directly relating the megafaunal, microfaunal, and microfloral assemblages in several outcrop sections would provide tools for much more accurate dating and correlation of subsurface Jurassic strata over all of the western interior.

No Jurassic strata exist in the northern part of the area as the result of pre-Blairmore erosion (Fig. 21). In the south, increasing age ranges of the formations away from the centre of the area reflects the presence of the ancestral Sweetgrass Arch. Onlap during marine transgression caused the basal beds of each formation to become younger toward the arch crest, while prolonged exposure promoted increased erosion when the seas regressed. Deep erosion of the Cut Bank and Whitlash Valleys produced the irregular top surface of the Swift Formation. These subtle relationships are documented by lithological correlation, and hence are shown only schematically.

B. Cretaceous Formations

Continental strata of the Blairmore Group host only floral and scattered microfaunal remains, and hence are much more difficult to date than the marine Jurassic strata. Marine strata equivalent to the Blairmore can be dated with confidence, but lie far to the north of the study area.

Megaflora

Bell (1956) published a complete and detailed investigation of Lower Cretaceous megafloras of western Canada. Two important conclusions resulted:

1. Three distinct floral assemblages can be recognized, which characterize the Kootenay Group, lower to middle Blairmore, and the upper Blairmore.
2. Almost all of the floral taxa are fairly long-ranging, so that it is difficult to assign precise age ranges.

The Kootenay and lower Blairmore floral assemblages share a large number of taxa, and are composed primarily of conifers, ferns, cycads, and ginkgos. In contrast, the upper Blairmore flora, which Bell found to be separated from the lower flora by about 200 feet of barren strata, is dominated by angiosperm taxa. Mellon and Wall (1963) collected a flora transitional between the two Blairmore assemblages from the northern Foothills.

The lower to middle Blairmore assemblage characterizes all the Cretaceous strata investigated in this thesis. Bell (1956) interpreted the most likely age of this assemblage as early Albian or Aptian, largely because he felt that it was not much older than the upper Blairmore flora, which he dated with confidence as Albian. Bell did realize that his arguments were not conclusive, however, and stated that a Barremian age for the lower Blairmore assemblage was possible. Gussow (1960), using the same evidence and comparing it with floras from the English Wealden strata, postulated that Blairmore deposition spanned earliest Cretaceous to Aptian time. Mellon (1967) pointed out that almost all collections of the lower Blairmore flora had been made from the Beaver Mines Formation, and that the Gladstone Formation is usually barren, an observation which casts even more doubt on the lower age range of Blairmore deposition. Clearly then, the megafloral evidence alone is insufficient for detailed age determination of the lower part of the Blairmore Group, and is useful only as a rough correlation tool.

Microflora

A comprehensive treatment of the Mannville microfloras was published by Pocock (1962), although his analysis was restricted to the lower part of the Mannville Group, equivalent to the Gladstone and basal Beaver Mines of the present nomenclature in southern Alberta. Pocock found that the palynomorph assemblages of the Deville, "Quartz sand", "Calcareous", and "Glauconitic" members (Table 3) are all distinct but still fairly similar. Environmental variations, particularly in the marine-influenced "Calcareous" and "Glauconitic" members, explain some of the differences. Pocock interpreted the Mannville assemblages, by comparison with English Wealden assemblages, to indicate that the Deville was deposited during the Berriasian to Valanginian, the "Quartz sand" during the Barremian, the "Calcareous" member during the upper Barremian, and the "Glauconitic" sand during the Aptian. As was the case for the Jurassic microfloras and Blairmore megafloras, however, many of the Mannville microfloral taxa are long ranging and consequently of limited use in age determinations. Pocock (1976) later changed his age interpretations to agree essentially with those of Singh (1964) (see below), although there appear to be significant differences between the groups of species regarded as index fossils by the two workers. On the basis of palynomorphs (particularly dinoflagellates) not documented in his earlier studies, Pocock assigned an Aptian age to the Deville and "Quartz sand" members, and a late Aptian age to the "Calcareous" member.

Singh (1964) considered only index species of microflora (those with a recognized restricted stratigraphic distribution) in the Mannville of east-central Alberta. Detailed comparison with English Wealden floras led him to conclude that the Deville is no older than late Barremian and that the Ellerslie (equivalent to the "Quartz sand") is Aptian in age. He dated the "Calcareous" member, which contains no index fossils younger than those in the Ellerslie, as early to early middle Albian on the basis of its stratigraphic position between the Aptian Ellerslie and the overlying marine middle Albian Clearwater Formation.

Microfauna

Few microfaunal taxa have been recovered from continental Blairmore strata of the thesis area, although more diverse assemblages have been recovered from correlative marine and transitional strata to the north. The "ostracod zone", described in Chapter IV, comprises the only coherent Cretaceous microfaunal assemblage below the Beaver Mines Formation in the thesis area. Loranger (1951) assigned an Aptian age to the "ostracod zone", based only on its association with the pelecypod Unio (Protelliptio) hamili. Badgley (1952) assigned an early Albian age to the "zone", again with little explanation. Gussow (1960) interpreted a Berriasian age for the fauna based on the presence of Metacypris pahasapensis which, as previously discussed, is a facies-controlled fossil and not a reliable age indicator. Mellon and Wall (1963) and Mellon (1967) concluded that the microfauna of the Protelliptio hamili zone (as it was called by Mellon (1967)) are not suitable for age determination, as the constituent taxa are too long ranging.

Megafauna

Marine megafaunas with well-defined age ranges do not exist in the Blairmore of the study area, but have been recovered in abundance from equivalent marine strata in northern Alberta and British Columbia (Stelck et. al, 1956;

Stelck, pers. communication). These strata can therefore be dated precisely in terms of standard ammonite zones (Jeletzky, 1967). Associated microfossil assemblages can be used to continue correlations into marginal marine strata (Stelck, _et_. _al_, 1956; Mellon and Wall, 1963; Mellon, 1967; Stelck and Kramers, 1980). Further extrapolation of the age ranges determined by marine megafaunas into continental deposits must be based entirely on lithostratigraphic correlation, although significant errors can occur because of diachronism of deposition. Ages determined in this manner agree well with the microfloral ages in the Mannville of central Alberta, but they cannot be applied with as much confidence to the Blairmore of the study area.

An important recent development is the discovery of the ammonite _Freboldiceras_ in the basal Grand Rapids Formation of north-central Alberta (Table 3). Stelck and Kramers (1980) interpreted the occurrence of this ammonite to indicate an early Albian age for the base of the Grand Rapids, which lies above the base of the Beaver Mines equivalent (see Chapter VI). This determination thus restricts the upper age limit of the Gladstone and equivalent strata to no younger than early Albian.

Conclusions

Fossil taxa of the Blairmore Group of the southern Alberta and northern Montana Plains cannot be interpreted to provide sharply-defined, unambiguous ages. The fossil megaflora is fairly homogeneous throughout the section, and indicates only an Early Cretaceous age. The microfauna is similarly long ranging, and its distribution is governed primarily by facies relationships. Detailed studies of the palynomorphs have led most workers to conclude that Aptian and Albian ages can be assigned to the Mannville of the central and northern Plains. More precise megafaunal dating of lithostratigraphically equivalent marine strata further restricts ages ranges, but these determinations are subject to some doubt because of regional diachronism of deposition.

VI. STRATIGRAPHIC CORRELATION WITH SURROUNDING AREAS

As stated in Chapter I, the present study area is essential to the understanding and correlation of several schemes of stratigraphic nomenclature. Figure 22 and Table 3 show the correlation of Upper Jurassic and Lower Cretaceous strata in the thesis area with strata of the same age in four adjacent areas: the Rocky Mountains and Foothills of southern Alberta to the west, the Plains of central Alberta to the north, the Plains of southwestern Saskatchewan to the east, and the Big Horn Basin of northern Wyoming to the south. The basic stratigraphic scheme in each area is well established, and in turn can be related with confidence to more distant areas.

Correlations are discussed for three intervals: Ellis Group equivalents, strata laid down during the time between Ellis and Blairmore deposition, and Blairmore Group equivalents. Lithostratigraphic correlation is the primary objective, but chronostratigraphic evidence is presented as well.

A. Ellis Group Equivalents

Marine strata of the Ellis Group are homogeneous over large areas, undergoing only gradual facies changes to the west, east and south. This homogeneity and the presence of abundant fossils lends a high degree of certainty to both lithostratigraphic and chronostratigraphic correlations.

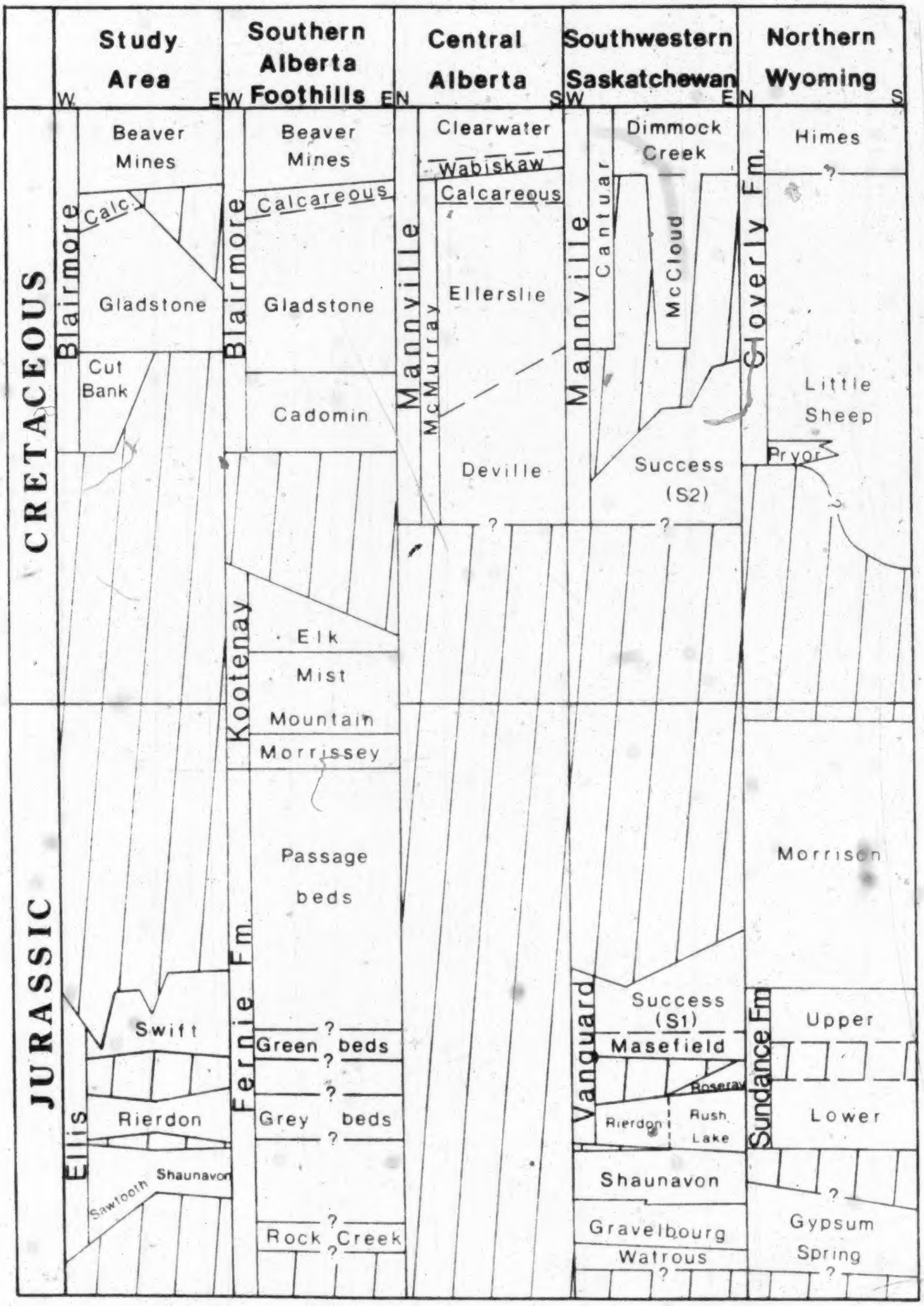

Study Area
W
E
Southern Alberta Foothills
W
E
Central Alberta
N
S
Southwestern Saskatchewan
W
E
Northern Wyoming
N
S
CRETACEOUS
JURASSIC
Blairmore
Beaver Mines
Calc.
Gladstone
Cut Bank
Ellis
Swift
Rierdon
Sawtooth
Shaunavon
Beaver Mines
Calcareous
Blairmore
Gladstone
Cadomin
Kootenay
Elk
Mist
Mountain
Morrissey
Fernie Fm.
Passage beds
Green beds
Grey beds
Rock Creek
?
Mannville
McMurray
Clearwater
Wabiskaw
Calcareous
Ellerslie
Deville
Mannville
Cantuar
Dimmock Creek
McCloud
Success (S2)
Vanguard
Success (S1)
Masefield
Roseray
Rierdon
Rush Lake
Shaunavon
Gravelbourg
Watrous
Cloverly Fm.
Himes
Little Sheep
Pryor
Morrison
Sundance Fm.
Upper
Lower
Gypsum Spring

Fig. 22. Correlation chart of strata in thesis area and those of surrounding areas. Southern Foothills after Mellon (1967), Gibson (1979), and Frebold (1957); Central Alberta after Williams (1963); Saskatchewan mod. after Christopher (1974); Wyoming after Moberly (1960) and Imlay (1956).

STUDY AREA		SOUTHERN ALBERTA		CENTRAL ALBERTA		SOUTHERN SASKATCHEWAN		CENTRAL MONTANA		WESTERN WYOMING	
							Pense				
BLAIRMORE	Beaver Mines	MANNVILLE Upper		MANNVILLE	Grand Rapids	MANNVILLE Cantuar	Atlas		Kootenai	GANNETT	
			Glauconitic		Clearwater		Dimmock Creek				? Bechler
	Calcareous	MANNVILLE Lower	Moulton	McMurray	Calcareous		McCloud				Peterson
	Gladstone		Sunburst		Basal Quartz / Quartz sand						Ephraim
	Cut Bank		Cut Bank		Deville		Success				
▨	▨	▨	▨	▨	▨	▨	▨		Morrison		Morrison
ELLIS	Swift	ELLIS GROUP		▨	▨	VANGUARD GROUP		ELLIS	Swift		Stump
	Rierdon			▨	▨				Rierdon		Preuss
	Sawtooth / Shaunavon			▨	▨		Shaunavon		Piper		Twin Creek
				▨	▨		Gravelbourg				
▨	▨	▨	▨	▨	▨		Watrous		Nesson		

Table 3. Formal and informal lithostratigraphic nomenclature, discussed in text, of southern Alberta and surrounding areas.

Southern Alberta Foothills

Marine strata of Middle and Late Jurassic age can be traced without interruption from the study area west to the Foothills and Rocky Mountains, where they are included in the Fernie Formation. The Ellis - Fernie transition is not defined and as the two units are very similar, an arbitrary cut-off would have to be designated to separate them. The Fernie, however, also includes older strata of Middle and Early Jurassic age and younger strata of Late Jurassic age. Frebold (1957, 1958) and Frebold _et al_. (1959) described the lithology and megafaunas of the Fernie in detail.

The Rock Creek member of the Fernie Formation (Fig. 22) is composed of uniform very dark, rusty-weathering shales with some bands of sandy limestone and limy sandstone, tending to become coarser-grained to the east (Frebold, 1958). It is thus quite similar lithologically to the lower part of the Sawtooth Formation of the western part of the thesis area. Frebold (1957, 1958) dated the Rock Creek as middle Bajocian, but was unable to make direct faunal correlations with the Sawtooth. He cited, however, Imlay's (1953) report of the ammonite _Chondroceras_ (_Defonticeras_) in the lower Sawtooth of southwestern Montana, and noted the occurrence of the same genus in the Rock Creek member.

Frebold (1957) described three major divisions of the lower Callovian Grey beds of the Fernie. In the Foothills west of the Alberta part of the thesis area, the _Corbula_ munda and the overlying Gryphaea beds crop out, which comprise just over 100 feet of grey shales with bands and lenses of greyish calcareous fossiliferous sandstone. In the upper four feet are the Gryphaea beds, which consist almost entirely of shallow-water molluscan fossils. Sixty feet of shale overlie these beds, although only the basal five feet yield fossils. Further west, approaching the Fernie (B.C.) area, Frebold's third division is found, as the Grey beds thicken to 225 feet, become less sandy, and lose their characteristic pelecypod fauna found in the Foothills. Frebold (1957) interpreted the age of the Grey beds to be early Callovian, as he found their megafauna to be correlative with the five Callovian faunal zones of the western interior United States outlined by Imlay (1947, 1952a) (see Fig. 21, this thesis). The Rierdon Formation is thus lithologically similar to the Grey beds, especially to the western shaly division, and is of the same age.

The Green beds of the Fernie Formation overlie the Grey beds (Fig. 22). In the Foothills west of the thesis area, the Green beds are composed of up to 50 feet of shallow-water glauconitic sandstone with yellow-brown concretions containing belemnites, gastropods, vertebrate remains, and plant debris (Frebold, 1957). To the north, the sandstones are replaced by dark shales with large concretions. The coincidence of shallow-water facies and faunas in the southern Foothills both in the Callovian (Corbula munda and Gryphaea beds) and the Oxfordian (Green beds) indicates the persistent presence of a relatively shallow area.

Frebold (1957) correlated the Green beds with the shale member of the Swift Formation, although he admitted that there had been insufficient recovery of index fossils from the Green beds to date and correlate them accurately. Some of the barren shales included in the upper part of the Grey beds may also be partly equivalent to the Swift shale member.

Gradationally overlying the Green beds are the Passage beds, which Frebold (1957) correlated with the ribbon sand member of the Swift Formation. The Passage beds consist of dark shales with thin interbeds of sandstone very similar to the ribbon sand. Sandstone content increases gradually upward, but never becomes as prevalent as it is in the type Swift. No index fossils have been found in the Passage Beds, but their stratigraphic position and lithology provide sufficient evidence for their correlation with the Oxfordian Swift Formation. Frebold (1957, 1958) and Frebold _et al_. (1959) suggested that the upper, sandier portion of the Passage beds is equivalent to the Morrison Formation (Fig. 22). This correlation is likely true, as will be discussed later, but the precise location of the transition from Swift to Morrison equivalent is unclear because of the lack of fossil evidence. As well, marine influence continued in the present-day Foothills area after the sea had withdrawn from the Plains (see Chapter VII).

In summary, the Middle and Upper Jurassic strata of the Fernie Formation can be correlated directly with the Ellis Group both lithologically and paleontologically. Some facies differences exist, but these can be attributed to the generally deeper-water depositional environments of the Fernie Formation and to local shoals in the southern Foothills area. Frebold's (1957, 1958) paleontological interpretations indicate that shorter periods of deposition are represented by the strata of the Fernie than by Ellis strata, a situation opposite to what would be expected when the environmental aspects are considered. Abundant shale strata lacking index fossils are contained in the Fernie, however, which were probably laid down during the intervals between Rock Creek, Grey beds, and Green beds deposition.

Central Alberta

No Jurassic strata are preserved to the north of the thesis area, as they are truncated at the northern erosional escarpment within the thesis area. Lower Cretaceous strata thus lie directly on Mississippian and Devonian formations in central Alberta.

Southwestern Saskatchewan

Christopher's (1964, 1974) stratigraphic nomenclature is the basis for most of the correlations discussed below. Some of his age assignments and correlations, however, require revision, as suggested in this section.

The Shaunavon Formation of the Williston Basin is directly correlative with the Shaunavon of the eastern part of the study area, although its basal beds become slightly older to the east into the Williston Basin because of onlap onto the Sweetgrass Arch. It is conformably overlain by the Rierdon and Rush Lake Shale of the Vanguard Group east of Longitude 108°, but a disconformity which increases in magnitude toward the Sweetgrass Arch is present at the top of the Shaunavon to the west (Christopher, 1974). Milner and Thomas (1954) named and described the Watrous and Gravelbourg Formations, which underlie the Shaunavon in the Williston Basin. These formations are equivalent in age to the lower part of the Sawtooth, although the lower age limit of the older Watrous has not been determined conclusively (Fig. 22).

The Rierdon Formation can be traced eastward from the Alberta - Saskatchewan border for about 65 to 90 miles (Christopher, 1974). Its lower contact is clearly defined by the limestone of the Shaunavon, while the Rierdon shoulder marks the top of the formation on geophysical logs. To the east, the upper beds become younger and eventually grade into fine-grained sandstone strata, at which point Christopher (1974) subdivided the Rierdon into the lower Rush Lake Shale and the upper Roseray Sandstone. Approximately 70 - 120 miles farther to the east, around Ranges 25 - 30W2M, Christopher claimed to recognize the Rierdon shoulder again and hence extended the Rierdon into this area.

The shale member of the Swift Formation is directly correlative with most of the Masefield Shale of Christopher (1974, 1980). Christopher (1974) observed some sand in the upper part of the Masefield, but such arenaceous strata are more logically included in the overlying Success Formation.

As defined by Christopher (1974), the Success Formation presents numerous correlation problems. Christopher assigned the Success to the Mannville Group, and postulated that it was deposited over a broad, low-relief erosional surface. He distinguished two informal subdivisions of interest in this study:

1. S1: generally coarsening-upward carbonaceous mudstones and quartzose siltstones to fine sandstones. Sandstones are fairly massive near the top, but occur in "pods and rolls" where transitional to lower mudstones. The S1 is often glauconitic near the base, and contains abundant small siderite spheres near the top.
2. S2: characterized by "macrolenticular" fining-upward sandstone bodies with abundant trough and tabular cross-stratification, grading up to small-scale trough cross-beds and ripple laminae. It sharply and unconformably overlies the S1 unit.

Christopher (1974) mapped the Success as a blanket-type deposit later removed from many areas by pre-Cantuar erosion. The S1 unit is truncated to the north and locally to the west and east of its type section near Swift Current

(Township 15, Range 14W3; Fig. 1) by the more widespread S2 unit.

Inclusion of the entire Success Formation in the Mannville Group is clearly erroneous when the Upper Jurassic - Lower Cretaceous stratigraphic succession in surrounding areas is considered. Christopher tentatively correlated the S1 unit with the Jurassic Morrison Formation, but various lines of evidence show that the S1 should be correlated with the ribbon sand member of the Swift Formation. Photographs by Christopher (1974) show the S1 lithotypes and accessory components to be very similar to those of the ribbon sand, an observation confirmed by re-examination of several cores. Christopher (1974) did not discuss the nature of the Masefield Shale - Success (S1) contact, but sandy beds observed in some cores of the upper Masefield signal the initiation of ribbon sand deposition, and therefore imply a gradational contact. He found the S1 - S2 contact, however, to be regionally unconformable. Finally, samples taken by the present author from two Success cores (Tidewater Frontier Crown 13-21-3-20W3, 4093 feet and 4136 feet; and Tidewater Staynor Crown 1-29-2-22W3, 4166 feet) yielded Late Jurassic palynomorph assemblages very similar to those found in the ribbon sand.

The S1 unit of the Success Formation is therefore considered to be correlative with the ribbon sand member of the Swift Formation. Patchy distribution of the S1 can be attributed to pre-Blairmore erosion and to the difficulty of correlating the eroded remnants of the S1 across large areas with poor core control. The ribbon sand - S1 lithosome is probably thicker and more widespread in the extreme southwestern part of Saskatchewan than mapped by Christopher (1974), as it can be correlated eastward with confidence from the three east - west cross-sections of this thesis.

In summary, the Rierdon and Shaunavon Formations of the thesis area can be correlated directly eastward into Saskatchewan. The Swift can also be traced into Saskatchewan, but there it has been divided into the Masefield Shale and the S1 unit of the Success Formation by Christopher (1974). For regional correlation purposes, the Masefield and S1 unit should be incorporated into one formation at the top of the Vanguard Group, and the S2 unit of the Success should be assigned to a separate, younger formation.

Northern Wyoming

Formations of the Ellis Group can be correlated southward with a high degree of confidence, although the Belt Island paleotopographic high (see Chapter VII; Fig. 24) influenced facies significantly and caused erosional truncation of each formation over various areas.

The Sawtooth Formation is recognized only north of the Belt Island high (Peterson, 1972). To the south, continental to restricted marine environments are indicated by the presence of abundant red beds and evaporites in the

Nesson and Piper Formations (Table 3; Rayl, 1956). Middle to late Bajocian ammonites recovered from the Piper show that it was deposited approximately synchronously with the normal marine Sawtooth (Imlay, 1956). Further south, the Nesson and Piper can be correlated lithologically with the Gypsum Spring Formation of the Big Horn Basin, which is composed entirely of red beds, gypsum, and thin limestone beds lacking diagnostic index fossils. It is disconformably overlain by the Sundance Formation; the truncation of marker beds to the south indicates that the magnitude of the unconformity increases in that direction (Imlay, 1956).

Rierdon Formation strata gradually become sandier and less calcareous to the south of the thesis area (Peterson, 1972). In southern Montana, Imlay (1956) distinguished a thin basal sandstone, a medial shale member, and an upper sandstone. He recognized the same lithological units in the Lower Sundance Formation of the Big Horn Basin, and documented the same megafaunal zones in the Lower Sundance as in the Rierdon of northern Montana.

Little difficulty is encountered in tracing the two members of the Swift Formation to southern Montana. The shale member becomes slightly calcareous, whereas the upper member becomes more strongly dominated by cross-bedded fossiliferous sandstones with thin interbeds of pelecypod coquinas. Similar lithologies in the Big Horn Basin of northern Wyoming make up the Upper Sundance Formation. Brenner and Davies (1974) included the shale member of the

Upper Sundance in the mud facies and the sandstone member in the marine bar sand facies of their Oxfordian depositional model. The molluscan fauna of the Upper Sundance, documented by Imlay (1956), provides evidence that this part of the Sundance is similar in age to the Swift of northern Montana. The Upper Sundance - Morrison boundary becomes somewhat older to the south because of the retreat of the Oxfordian sea to the north.

B. Post-Ellis, Pre-Blairmore Strata

Although no rocks of post-Oxfordian, pre-Aptian age have been identified in the thesis area, sediments accumulated in nearby areas during this time. These strata are discussed briefly because of their importance to the reconstruction of the Late Jurassic - Early Cretaceous geological history of the western interior.

Southern Alberta Foothills

Deposition of the Passage beds of the Fernie Formation continued uninterrupted in the West Alberta Basin long after the withdrawal of the Swift (Oxfordian) sea from the Sweetgrass Arch area. Continued shallowing of the sea is recorded by the increased sand content toward the top of the Passage beds (Frebold, et al., 1959), much as the Swift ribbon sand coarsens upward. The contact of the Passage beds with the massive sandstone at the base of the overlying Kootenay Group is transitional, and several workers have debated its exact position (Frebold, 1957; Jansa, 1972;

Gibson, 1977, 1979). Gibson (1977, 1979) and Hamblin and Walker (1979) designated the base of a massive, cliff-forming sandstone to be the base of the Kootenay.

Gibson (1979) formalized the stratigraphy of the Kootenay Group, subdividing it into three formations. The basal Morrissey Formation is a massive, coarsening-upward sequence of sandstone up to 80 metres thick. The Mist Mountain Formation comprises as much as 665 metres of interbedded sandstone, siltstone, mudstone, shale, and coal. As much as 590 metres of interbedded sandstone, siltstone, mudstone, coal, and locally thick chert pebble conglomerate make up the upper Elk Formation. Gibson and Hughes (1981) provided a detailed depositional model for the entire Kootenay, consolidating and further developing previous models by Gibson (1977) and Hamblin and Walker (1979). All three models suggest that the Late Jurassic sea had retreated from the craton and was retreating from the West Alberta Basin as well during Kootenay time.

Insufficient paleontological evidence exists to date the Passage beds and Kootenay Group precisely. Frebold (1957) reported the occurrence of the late Portlandian ammonite Titanites occidentalis from the Morrissey Sandstone. Because of their conformable contacts with the Morrissey and the Green beds, the Passage beds were assigned a Kimmeridgian to early Portlandian age. The Kootenay would therefore be latest Jurassic to earliest Cretaceous in age, with the Jurassic - Cretaceous boundary possibly lying somewhere within the Mist Mountain Formation (Gibson, 1979). This entire dating scheme depends upon the tentative identification of a single specimen of a giant ammonite, of which only the outer whorls are preserved (Frebold, 1957; p.66, Plates XLII - XLIV). C.R. Stelck (pers. communication) has indicated tht the identification of this specimen may be called into question because it is not sufficiently well preserved to warrant its assignment to a particular genus. If the "Titanites" specimen actually belongs to a Kimmeridgian or even late Oxfordian genus, as suggested by Stelck, the ages of the Passage beds and Kootenay Group would have to be increased correspondingly. The Kootenay would then perhaps be entirely Late Jurassic in age.

No strata correlative to the Kootenay are found in the thesis area, as the group is erosionally truncated near the eastern edge of the Foothills. The interval of erosion and nondeposition shown in Fig. 22 includes most of Neocomian (Berriasian to Barremian) time in the Foothills, but the hiatus could be much larger if the Kootenay proves to be entirely Jurassic in age.

Southwestern Saskatchewan

Extensive erosion and little deposition took place over southwestern Saskatchewan during the latest Jurassic - earliest Cretaceous interval. The S2 division of the Success Formation was correlated with the Deville Member of the Mannville Group of central Alberta by

Christopher (1974), and was thus included in the Mannville of southern Saskatchewan. Both the Deville and Success S2 are discussed in the following section on Blairmore-equivalent strata.

Northern Wyoming

To the south of the study area, the Morrison Formation was deposited in terrestrial environments as the Swift sea retreated from the craton (see Chapter IV). The Morrison is well developed in the Great Falls, Montana area (Walker, 1974), and can be traced continuously southward throughout the western interior of the United States (Suttner, 1969; Peterson, 1972). In the Big Horn Basin of northern Wyoming, the Morrison consists of 130 to 280 feet of lenticular mudstones, siltstones, and sandstones which are exposed primarily in areas of badland topography (Moberly, 1960). These strata were laid down in fluvial floodplain and channel as well as lacustrine environments (Moberly, 1960; Peterson, 1966).

The conformable contact of the Morrison of the Big Horn Basin (and of most other areas) with the underlying Oxfordian Sundance Formation is evidence of a Kimmeridgian age. Yen (1951) described a molluscan fauna from the Morrison which he interpreted to be older than Purbeckian (latest Jurassic), and Imlay (1952) summarized other paleontological evidence for the Late Jurassic age of the Morrison.

The Morrison - Cloverly (lowest Cretaceous) contact is not conspicuous in most of the Big Horn Basin because of the similar lithologies of the two formations, and Moberly (1960) proposed that the nondepositional hiatus between the two was very small.

C. Blairmore Group Equivalents

Continental strata of Early Cretaceous age are found over the entire western interior of North America, recording renewed deposition after a long hiatus as the result of uplift of western orogenic and northeastern Precambrian Shield source areas. Lowermost Cretaceous strata are thus regionally diachronic because of the variable timing of local source area uplift. Poor paleontological control hinders the accurate correlation of depositional events, and therefore the ages shown in Fig. 22 are subject to modification.

Southern Alberta Foothills

Little discussion is necessary in this section, as the Cretaceous lithostratigraphy of the thesis area is derived from that of the Foothills.

The Cadomin Formation of the Foothills is equivalent to the Cut Bank Formation of the study area. Conglomerate with chert, orthoquartzite, argillite, and siltstone pebbles and a coarse quartz-chert sand matrix is the dominant lithology of the Cadomin, occurring interbedded with variable proportions of coarse- to medium-grained siliceous sandstone. The pebble percentage and clast size generally increase westward (Schultheis and Mountjoy, 1978). The Cadomin is up to 200 metres thick, although it rarely exceeds 15 metres in the southern Foothills (McLean, 1977). Considering the homogeneity and large areal extent of the formation, it is uniformly quite thin.

Schultheis and Mountjoy (1978) and McLean (1977) agreed that the Cadomin accumulated (from west to east) as pediment gravels, in coalescing alluvial fans, and in alluvial plain environments. In southern Alberta, the finer deposits of the easterly, north- to northwest-flowing river system are included in the Cut Bank Formation. To the north, all the sediments are included in the Cadomin, although more detailed study may justify the designation of other formations composed primarily of sandstone.

The Gladstone and Beaver Mines Formations thicken markedly westward from the thesis area to their erosional truncation in the Rocky Mountains.

Central Alberta

Strata equivalent to the Blairmore of the study area can be traced northward without interruption through central Alberta to an outcrop edge adjacent to the Precambrian Shield in northern Alberta and Saskatchewan. These strata are assigned to the Mannville Group over most of the area.

Nauss (1945) designated the type Mannville as a sequence of grey to grey-green continental and marine sandstones, shales, and coal. He divided the succession into six members, but most of these can be recognized only locally (Mellon, 1967). Williams (1963) described the formal lithostratigraphy of the Mannville of central Alberta (Fig. 22), which Mellon (1967) discussed and correlated throughout Alberta.

The basal Deville Member of the McMurray Formation consists of fragments of the underlying Mississippian and Devonian carbonates in a matrix of green, brown, and red claystones, coal, and thin sandstones (Williams, 1963). It is restricted to paleotopographical lows on the pre-Mannville erosion surface, and has been interpreted by Mellon (1967) to represent the residual weathering detritus derived from the Paleozoic carbonates. Beds which match the description of the Deville were found in cores from a very few wells in the northern two townships of the thesis area, north of the Jurassic escarpment (eg. R.O. Corp. East Alder 12-10-15-10W4, 3101-3114 feet; Appendix A, p. 290). Insufficient data were obtained to map or describe these beds adequately, so they were not differentiated from the Gladstone. It appears, however, that the Deville Member can be extended southward to the edge of the Jurassic escarpment.

Accurate dating of the Deville Member is not possible, as it is the product of long-term weathering, and thus varies in lithology and age from place to place. Most of it must be Early Cretaceous in age, however, as it is found in valleys cut during and immediately prior to deposition of the Mannville (Williams, 1963). Pocock (1962) recovered palynomorph assemblages from the Deville similar to those found in the Ellerslie, sufficient evidence to establish an Early Cretaceous age. At least a part of the Deville Member must therefore have been deposited at the same time that the Cut Bank Formation was being laid down to the southwest.

Grading up from the Deville is the Ellerslie Member (also called the "Basal Quartz"), a sequence composed of kaolinitic quartz sandstone, siltstone, and silty, micaceous, often carbonaceous shale. In central Alberta, the Ellerslie was deposited in fluvial - continental environments on a surface of moderate relief over Paleozoic carbonates and thin beds of the Deville Member (Williams, 1963; Rudkin, 1964). The Gladstone of the Blairmore Group is directly correlative with the Ellerslie on the basis of stratigraphic position, sandstone composition, and general depositional environments. Ellerslie strata are more widespread and blanket-like than those of the Gladstone, reflecting the dominance of aggradation over erosion in the broader valleys of the central and northern Plains near the edge of the advancing Boreal sea (Rudkin, 1964).

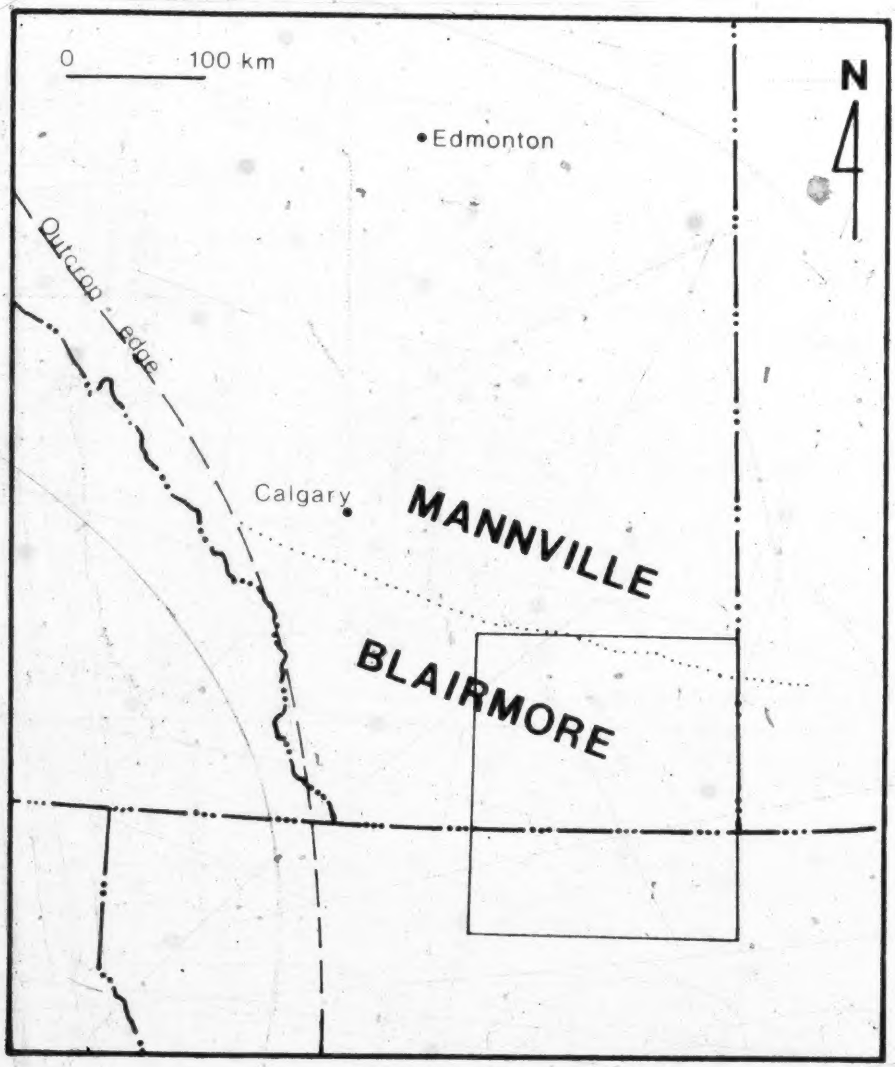
The "Calcareous" member of the McMurray Formation gradationally overlies the Ellerslie in central Alberta, and consists of dark calcareous fossiliferous shale, silty shale, and lenticular calcareous sandstones (Williams, 1963). It contains fresh water to brackish microfossils which become more marine to the north (Loranger, 1951; Glaister, 1959; Pocock, 1962). The "Calcareous" member of the Mannville is lithostratigraphically correlative with the "Calcareous" member of the Blairmore in southern Alberta. A broad, low-lying plain dominated by shallow lakes is envisaged as the depositional environment in which such widespread lacustrine to marginal marine facies accumulated (see Chapter VII).

The McMurray Formation grades sharply upward into the Clearwater Formation. In central Alberta, the base of the Clearwater is marked by a persistent very fine- to medium-grained glauconitic sandstone called the Wabiskaw Member by Badgley (1952) and Williams (1963). The remainder of the Clearwater consists of dark grey shales and silty shales, and very fine- to medium-grained "salt-and-pepper" sandstones, which contain much more feldspar and a generally greater proportion of rock fragments than sandstones of the McMurray Formation (Williams, 1963). A marine environment is indicated by the abundance of glauconite and the presence of marine microfossils (Pocock, 1962; Mellon and Wall, 1963). On the basis of stratigraphic position and sandstone composition, the Clearwater correlates with the Beaver Mines Formation of southern Alberta.

It is clear that the Blairmore of southern Alberta can be correlated directly with the Mannville of central Alberta. The contact between the two groups must be quite gradational, and must vary with stratigraphic position. An arbitrary cut-off (after Mellon, 1967) is thus designated to separate the Blairmore and Mannville in Fig. 23. South and west of the cut-off, drill hole cores indicate that red beds like those in the Blairmore type sections characterize the stratigraphic succession, while to the north and east, green- and grey-coloured beds more closely resembling the type Mannville predominate (Glaister, 1959; Mellon, 1967).

Southwestern Saskatchewan

Tracing Blairmore strata eastward into Saskatchewan is somewhat more difficult than tracing them northward into central Alberta. Much of the difficulty can be attributed to the sharply different scheme of stratigraphic nomenclature employed by Christopher (1974, 1980) in Saskatchewan. Christopher (1974) correlated the entire Success Formation with the Deville Member of central Alberta and Saskatchewan, postulating that both units had been laid down over a long indeterminate period of time prior to the commencement of deposition of the Gladstone - McMurray - Cantuar lithosome. In the broader regional scheme of sedimentation being considered in this thesis, only the S2 unit is correlated with the Deville, as the S1 unit has been shown to be equivalent to the Swift Formation. The erosional hiatus which straddles the Jurassic - Cretaceous boundary in Saskatchewan thus occurs between the S1 and S2 units of the Success, not at the base of the Success as proposed by Christopher (1974).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N
Edmonton
Outcrop edge
Calgary
MANNVILLE
BLAIRMORE

Fig. 23. Location of arbitrary cut-off line, based on subsurface data, separating the Blairmore and Mannville Groups in southern Alberta (after Mellon, 1967).

Most recent workers have included the strata of the Lower Cretaceous of Saskatchewan in the Mannville Group (eg. Maycock, 1967; Christopher, 1974, 1975, 1980), although there has been considerable disagreement regarding this nomenclature. Considering the position of the Blairmore - Mannville boundary in Alberta (Fig. 23) and the nature of the Saskatchewan strata (as described by Maycock (1967) and Christopher (1974, 1975)), the Lower Cretaceous strata of western Saskatchewan are best assigned to the Mannville Group, except in the extreme southwestern corner of the province, where they belong to the Blairmore.

Mannville strata overlying the Success are divided into the lower Cantuar and upper Pense Formations (Price, 1963) (Fig. 22, Table 3). The Cantuar fills in a high-relief unconformity throughout Saskatchewan, resting on Shaunavon, Rierdon, Masefield, and Success strata (Christopher, 1974). Three formal members of the Cantuar were designated by Christopher; these are the (lowest) McCloud, Dimmock Creek, and (highest) Atlas. The McCloud consists of quartzose sandstones with a kaolinitic to siliceous matrix at the base grading up to dark grey coaly shales, which fill in the lower part of large valleys. Most of the rest of the relief is filled in by the Dimmock Creek, which is characterized by argillaceous sandstones containing abundant feldspar, biotite, chlorite, and lithic fragments, as well as some glauconite. Similar sandstones typify the Atlas Member, which forms a blanket deposit over the resulting low-relief surface.

Post-Success uplift of the Sweetgrass Arch - Swift Current Platform (Fig. 24) caused the development of major valley systems in which the fluvio-continental McCloud Member was deposited (Christopher, 1974). The McCloud is thus directly equivalent to the Gladstone of the thesis area. Similarly, the influx of feldspathic and lithic detritus which characterizes the Dimmock Creek and Atlas Members reflects the same event(s) which caused the onset of Beaver Mines deposition in southern Alberta and northern Montana.

Northern Wyoming

Basal Cretaceous continental strata in northern Wyoming make up the Cloverly Formation, which averages 280 to 300 feet thick in the Big Horn Basin, where Moberly (1960) has subdivided it into three members: the Pryor, Little Sheep, and Himes. The Pryor Conglomerate is a distinctive basal member occurring primarily on the northeastern side of the basin. It consists of chert pebble conglomerate and siliceous, locally coaly sandstone, which grades to thin well-sorted quartz arenites away from its depocentres, and grades upward into the lower beds of the Little Sheep Member. The Little Sheep is primarily a variegated bentonitic mudstone characterized by a "gumbo" weathering surface. A tuffaceous mudstone bed just below the top, and horizons of calcareous nodules in the upper part of the member interrupt the mudstone sequence. Variably-developed beds of quartz-chert arenite and conglomerate with limestone lenses similarly break up the lower part of the member. The upper Himes Member comprises about 100 feet of cliff-forming variegated sandstones and mudstones, often with a distinctive olive-grey cross-bedded sandstone at the base. This sandstone contains a high proportion of lithic grains as well as abundant partly-decomposed feldspar in a muddy matrix which swells on contact with water. Shoestring-shaped bodies of quartz arenite displaying sequences of sedimentary structures indicative of a fluvial environment are also common in this member.

The Cloverly correlates roughly with the Blairmore of southern Alberta and northern Montana (Walker, 1974; Suttner, 1969), although the lithologies are similar only in general nature, as a much greater proportion of volcanic debris is present in the south throughout the section. The Pryor Conglomerate correlates in lithology, genesis, and approximately in stratigraphic position with the Cut Bank and Cadomin Formations, while the Little Sheep Member is correlative with the Gladstone Formation. Finally, the Himes correlates lithostratigraphically with the Beaver Mines, although the uplift and erosion of western source areas which controlled sandstone petrology in the Big Horn Basin did not necessarily proceed at the same rate as similar activity several hundred miles to the north. No direct analogue for the "Calcareous" member of the Gladstone can be found in the Big Horn Basin, although Glass and

Wilkinson (1980) documented the occurrence of extensive Lower Cretaceous lacustrine facies of the Peterson Limestone to the west in western Wyoming and southeastern Idaho.

Lithological similarity of the Cloverly and the Morrison in the present-day Big Horn Basin and the lack of contrary fossil evidence led Moberly (1960) to suggest that Cloverly deposition followed immediately upon the termination of Morrison deposition and continued until the Aptian. The Morrison - Cloverly hiatus may therefore not be as large as shown in Fig. 22, and the Cloverly may be at least partly contemporaneous with the Deville Member of central Alberta and Saskatchewan.

VII. GEOLOGICAL HISTORY

Lithostratigraphic and chronostratigraphic schemes established for the thesis area in Chapters IV and V and external correlations established in Chapter VI can now be used to reconstruct the geological history of the western interior for the Late Jurassic and part of the Early Cretaceous.

A number of workers have summarized the history of parts of this area for part of this time interval (Imlay, 1957; Peterson, 1957a, 1972; Schmitt, 1953; Klingspor, 1958; Glaister, 1959; Rudkin, 1964; McGookey _et al_., 1972). None, however, has made a detailed analysis spanning the entire Late Jurassic - Early Cretaceous interval, and most treatments have been confined to either Canada or the United States. The critical transition area represented by this thesis therefore has not been adequately analyzed. In addition, paleogeographical interpretations can now be improved in light of recent information regarding the development of the Columbian and Nevadan Orogens.

Figure 24 depicts the major paleotectonic elements which influenced sedimentation during the Late Jurassic and Early Cretaceous. The stable craton, which is subdivided into the Alberta Shelf, Williston Basin, and Wyoming Shelf, makes up the eastern part of the map. The Alberta Shelf slopes westward into the Alberta Trough, and the Wyoming Shelf slopes westward into the Utah - Idaho Trough. Between

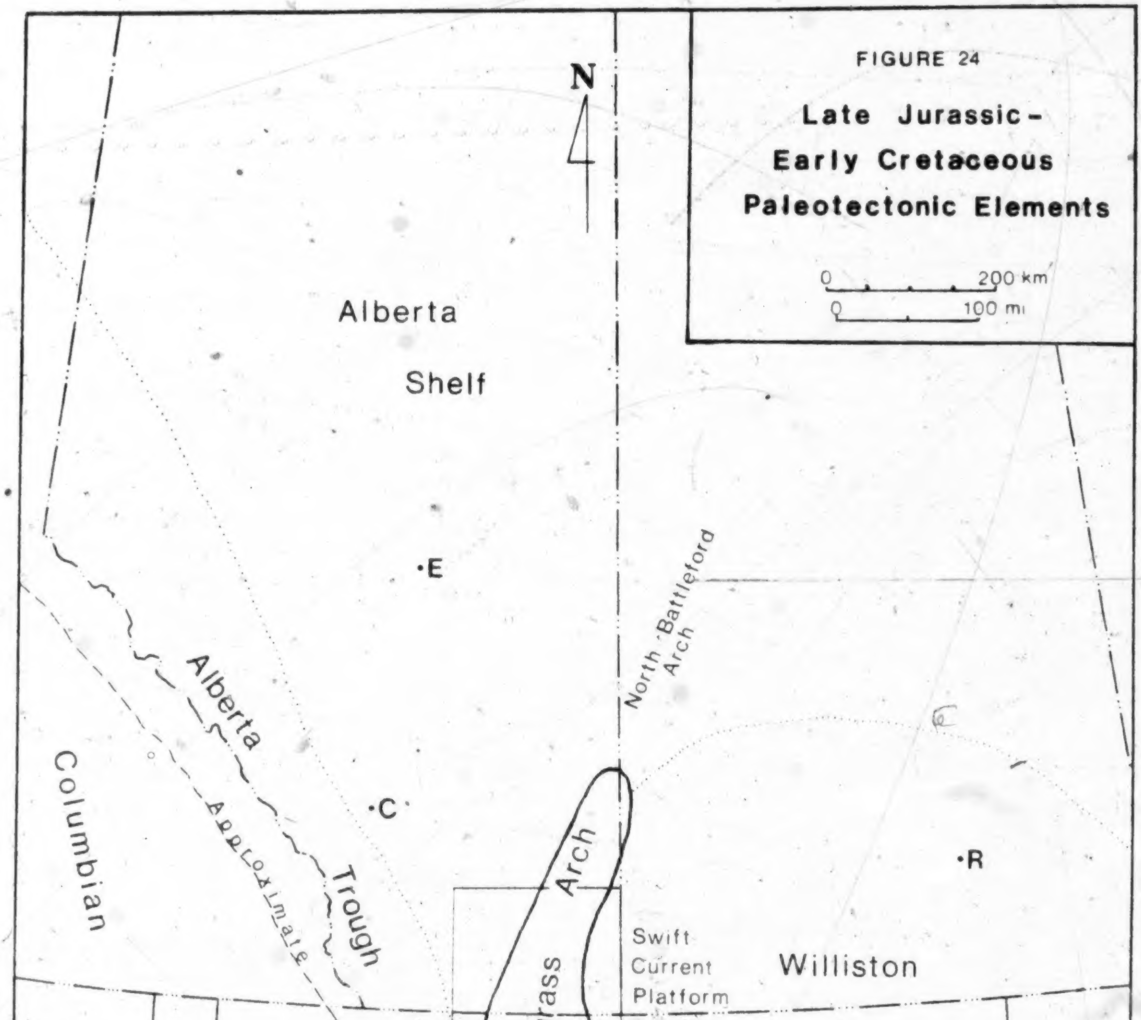


FIGURE 24
Late Jurassic - Early Cretaceous Paleotectonic Elements
0 200 km
0 100 mi
N
Alberta Shelf
•E
North Battleford Arch
Alberta Trough
Columbian
•C
Approximate limit
Sweetgrass Arch
Swift Current Platform
Williston Basin
•R
•G
Nevadan Orogen
Belt Island
•B
Wyoming Shelf
Utah-Idaho Trough
•Cs

Source: after Peterson (1957a)

these areas lie the Sweetgrass Arch and the Belt Island trend, which is a paleotectonic high, continuous with the Sweetgrass Arch and in part coincident with the South Arch of Tovell (1958) (Fig. 5b).

Jurassic and Cretaceous strata are truncated abruptly in the western part of the map area by Laramide (Late Cretaceous - Early Tertiary) overthrusting, uplift, and consequent erosion. Events which occurred in the Columbian and Nevadan Orogens during the Late Jurassic and Early Cretaceous must therefore be correlated by indirect means such as dating of intrusions, analysis of sedimentary strata in successor and intermontane basins, and structural relationships. Price et al. (1981) summarized concisely the events which took place in the Columbian Orogen during the Jurassic and Cretaceous. Davis et al. (1978) and Hamilton (1978) published similar compilations for the American section of the Cordillera.

Numerous transgressions and regressions of the sea took place over the broad cratonic platform during the late Mesozoic. At least five major advances can be documented during the Middle to Late Jurassic and Early Cretaceous alone. During this interval, orogenic uplift to the west progressively restricted marine Pacific access to the interior, although a Pacific connection existed through northern British Columbia in the Late Jurassic. The Transcontinental Arch, which trends northeastward through Utah, Colorado, and Nebraska, was not breached during the time interval considered here (Williams and Stelck, 1975), and thus there was no communication with the southern Gulfian sea.

Seven sub-intervals are considered here: Middle Jurassic, Callovian, Oxfordian, latest Jurassic - early Neocomian, late Neocomian - middle Aptian, middle Aptian - earliest Albian, and early Albian. Each subdivision corresponds to a major depositional sequence.

A. Middle Jurassic

Four major transgressive pulses took place over western North America during the Jurassic. The first sea advanced in the Early Jurassic, flooding only the Alberta Trough and depositing the lower part of the Fernie Formation.

Figure 25 is a generalized paleogeographical reconstruction of the western interior during the Middle Jurassic, when the second transgressive pulse took place. To the west, the earliest stages of a major orogenic episode were beginning. Convergent plate motions moved a number of small orogenic land masses, collectively referred to as "composite allochthonous terrane I" by Price *et al*. (1981) toward the craton in what is now south-central British Columbia and northeastern Washington. Similar movements of more southerly volcanic arc complexes toward the craton have been documented by Hamilton (1978). The incipient collision of these allochthonous terranes with the craton and with one another began to compress, shear, and thrust older

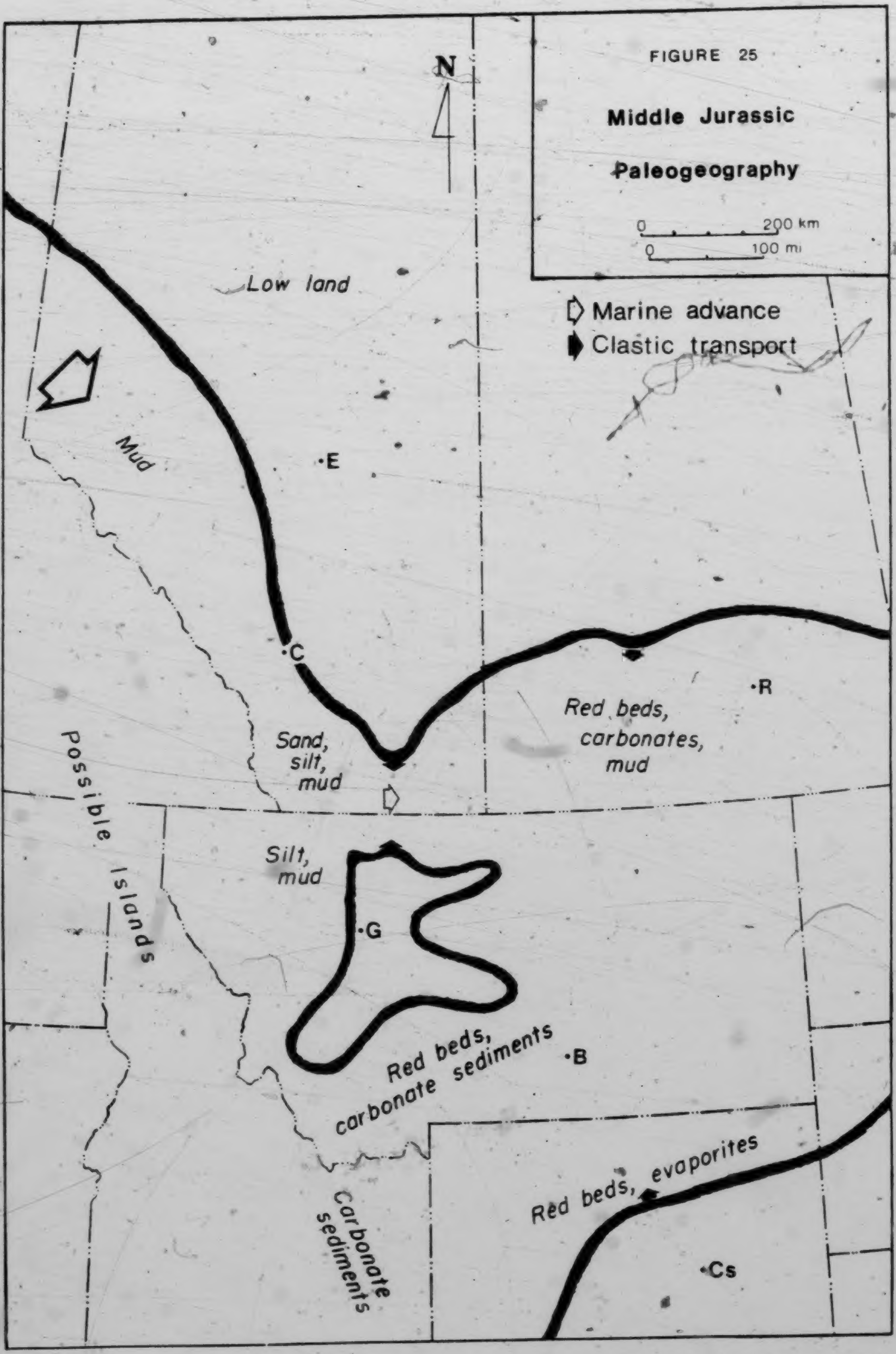


FIGURE 25

Middle Jurassic Paleogeography

N
0 200 km
0 100 mi
Marine advance
Clastic transport
Low land
Mud
E
C
R
Red beds, carbonates, mud
Sand, silt, mud
Possible Islands
Silt, mud
G
Red beds, carbonate sediments
B
Carbonate sediments
Red beds, evaporites
Cs

Shaded lines represent approximate shoreline positions

miogeoclinal strata eastward onto the craton. As large areas were uplifted, these strata assumed increased importance as sources of clastic sediment. In the Middle Jurassic, however, this process was just beginning, hence only scattered islands were present to the west; local sources must have accounted for most of the clastic sediment deposited.

As the sea advanced, shallow-water deposits of the middle Fernie Rock Creek member were laid down. Frebold (1957) assigned a middle Bajocian age to the Rock Creek, but unfossiliferous shales overlying this member were probably deposited in deeper water as the transgression continued.

Belt Island and the Sweetgrass Arch profoundly affected patterns of marine advance and water circulation, and were locally significant sediment sources. In the early stages of the transgression, normal marine siltstone and shale of the Sawtooth Formation were deposited north and west of the Sweetgrass - Belt Island land mass. Most of Belt Island was never covered or was inundated only briefly, as no Middle Jurassic strata are preserved over it. To the south and east, continental and restricted marine evaporites were deposited as the Watrous Formation in Saskatchewan, the Gypsum Spring in northern Wyoming, and the Nesson and Piper Formations in Montana and North Dakota. Wall (1960) found the foraminifera of the Shaunavon and the Sawtooth to be dissimilar, implying the existence of a Sweetgrass Arch barrier throughout most of the Middle Jurassic.

Continued transgression led to more open marine circulation throughout the western interior. Normal marine facies were deposited almost everywhere, including part of the Twin Creek Limestone in the subsiding Utah - Idaho Trough, the Piper Formation in Montana and North Dakota, and the Gravelbourg and Shaunavon Formations in Saskatchewan (Table 3, Fig. 22). Restricted conditions persisted in northern Wyoming, although the middle member of the Gypsum Spring Formation does contain some marine limestones with normal marine megafauna (Imlay, 1956). The Sweetgrass Arch was probably breached during the Bathonian. Relief on the Mississippian surface was considerable, and probably was important in controlling the topography of a low chain of islands along the arch trend. The Sawtooth and Shaunavon are consequently thin (locally absent) and sandy in this area.

During the latest Bathonian and earliest Callovian, some regression took place, with restricted marine facies bearing marginal marine to brackish microfaunal and microfloral assemblages again predominating (Wall, 1960; Pocock, 1972; Brooke and Braun, 1972). Deposition in the Alberta and Utah - Idaho Troughs and in the centre of the Williston Basin continued without interruption.

B. Callovian

During the early Callovian, the third Jurassic transgressive pulse flooded the craton to an even greater extent than did the Middle Jurassic advance (Fig. 26). A thick sequence of volcanic rocks and coarse sediments in northern British Columbia and the Yukon records episodes of island arc volcanism and flysch deposition during the late Middle Jurassic and early Late Jurassic (Eisbacher *et al*., 1974). Such activity was confined to regions lying substantially west of the craton, as no major allochthonous terranes had yet moved into full contact with the thick miogeoclinal sequence at the craton edge (Rudkin, 1964; Price *et al*., 1981).

In the Alberta Trough, grey shales of the Grey beds member of the upper Fernie Formation were deposited. A shoal, probably directly connected to the craton, was the locus of deposition of the shallow-water arenaceous, calcareous, and fossiliferous *Corbula munda* and *Gryphaea* beds.

Advance of the sea over the craton during the Callovian was again impeded by the Sweetgrass Arch and Belt Island; Peterson (1972) postulated that Belt Island had been submerged at the time of maximum transgression, but both the present author and Cobban (1945) observed substantial depositional thinning of the Rierdon at the northern edge of the trend. It thus appears most likely that the central region of Belt Island stood above the sea for the entire

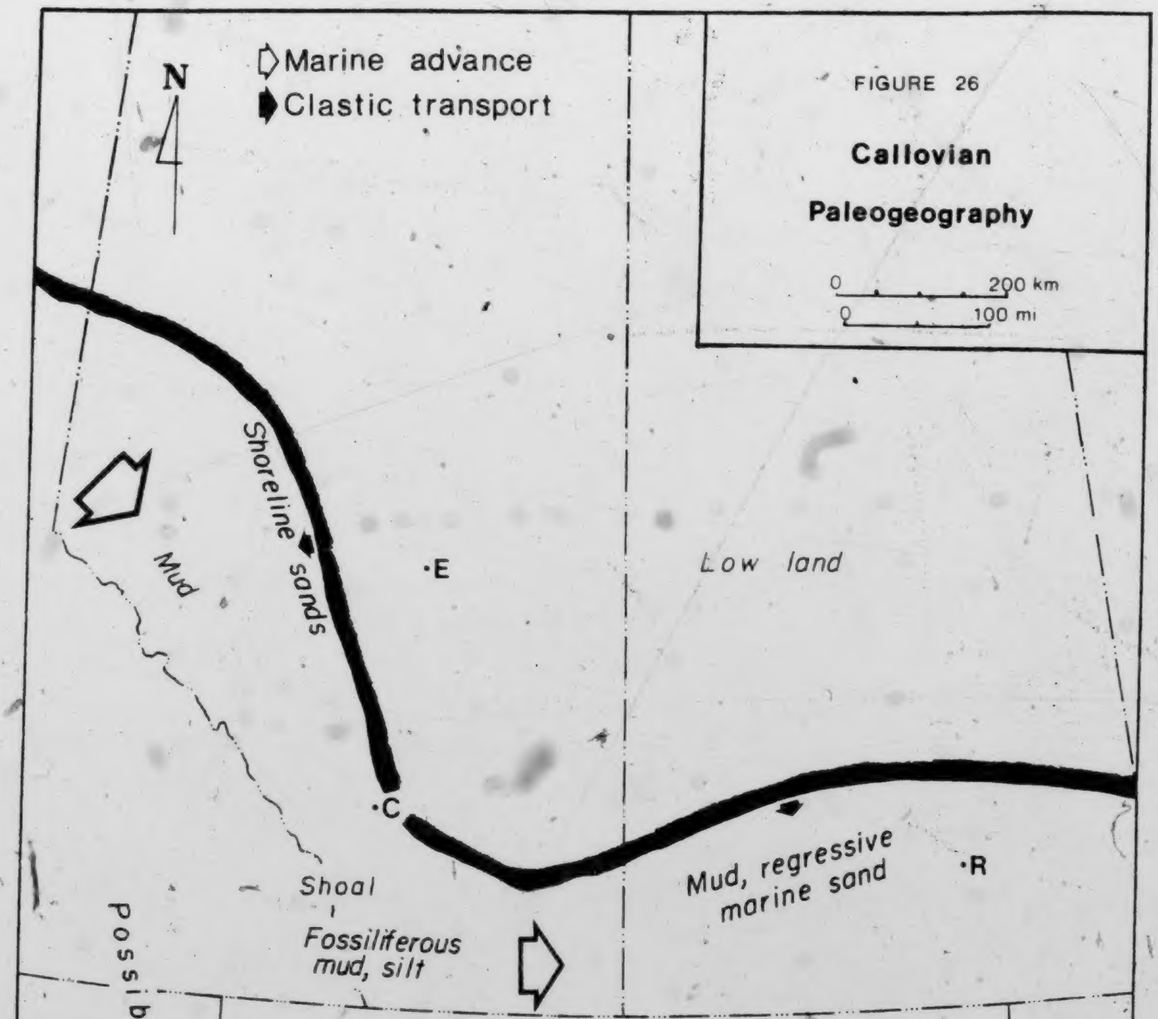

N
Marine advance
Clastic transport
0 200 km
0 100 mi
Shoreline sands
Mud
E
Low land
C
Shoal
Fossiliferous mud, silt
Mud, regressive marine sand
R
Possible Islands
G
Mud, calcareous mud
B
Sheridan Arch
Micritic mud, carbonate sediments
Nearshore sand, mud
Cs

FIGURE 26

Callovian Paleogeography

Shaded lines represent approximate shoreline positions

Callovian, although it shed very little clastic detritus.

Throughout most of the early Callovian, very homogeneous calcareous green-grey to grey shales and argillaceous limestones were laid down in the broad, shallow epeiric sea. These strata are included in the Rierdon Formation in southern Alberta and Saskatchewan and northern and western Montana, and in the Lower Sundance Formation in the remainder of the western Williston Basin. The paleoshoreline on the northern and eastern flanks of the Rierdon - Lower Sundance sea probably lay well beyond the present eroded margins, as little evidence of nearshore deposition has been found. In northern Wyoming, the Lower Sundance thins across a low paleotectonic positive feature called the Sheridan Arch (Fig. 26); to the south and east, the shales are more arenaceous and indicate a slightly shallower environment of deposition. Rautmann (1975) suggested that the Lower Sundance in this area was deposited as a sequence of submarine sand waves or tidal current ridges. Red beds, sandstones and evaporites were deposited in shallow marine to restricted environments near the southern margins of the sea (Imlay, 1957; Peterson, 1972), which generally remained outside the Fig. 26 map area. Thick limestones of the upper Twin Creek Formation accumulated in the Utah - Idaho Trough, which continued to subside throughout the Callovian.

Wall (1960) found that a large number of ostracod and foraminifera species are common to the Rierdon of Montana and the Rierdon - Rush Lake of Saskatchewan, although Peterson (1954) showed that the ostracod population of the Lower Sundance southeast of the Sheridan Arch differs significantly from the Rierdon assemblage. These microfaunal data thus support the concept of very open marine circulation over the western interior except for the portion of the cratonic basin southeast of the Sheridan Arch.

Shallow marine and tidally-influenced shoreline sand bodies were deposited as the sea regressed again during the late Callovian. In northern Wyoming, glauconitic, oolitic sandstones were laid down in submergent bar complex and barrier island environments (Rautmann, 1975). Christopher (1974) constructed a regional facies model for the Roseray Sandstone of southern Saskatchewan, showing that it was deposited as large tabular sandstone and siltstone bodies which he called "clinobeds". Each of his clinobeds represents a sheet of sediment deposited in shoreline to distal (but shallow) offshore environments, with each clinobed arranged in an offlapping sequence indicative of a regression, except for a small interval near the top of the formation where onlapping clinobeds indicate minor transgression.

As the regression continued, Belt Island and the Sweetgrass Arch once again became emergent, and significant erosion of the Rierdon occurred over paleotectonic highs. Red beds, evaporites, and nearshore to continental sandstones continued to accumulate in saline lagoon and continental environments to the south and southeast of the map area in Fig. 26 (Imlay, 1957). Subsidence in the Utah - Idaho Trough ceased in the late Callovian in response to orogenic uplift to the west, terminating deposition of the Twin Creek Limestone.

C. Oxfordian

During the early Oxfordian, marine waters flooded a somewhat greater area than was submerged during the Callovian (Fig. 27). Orogenic uplift in southern British Columbia became significant in the Oxfordian. Composite allochthonous terrane I of Price _et al_. (1981) had moved close enough to the craton to come into contact with the thick Paleozoic to Triassic miogeoclinal succession in the Alberta Trough, consequently uplifting and thrusting this sequence eastward. To the south, the miogeoclinal wedge was also thrust cratonward in response to the eastward movement of smaller allochthonous terranes. As the newly-uplifted land began to shed clastic debris, true molasse sedimentation was initiated in the foreland basin.

At the time of maximum transgression, sediments were deposited as shown in Fig. 27. Dark marine shales with large ironstone concretions were deposited in the northern and central Alberta Trough, while glauconitic fossiliferous shallow marine sandstones of the Green beds of the Fernie accumulated over the shallow area in the southern Alberta

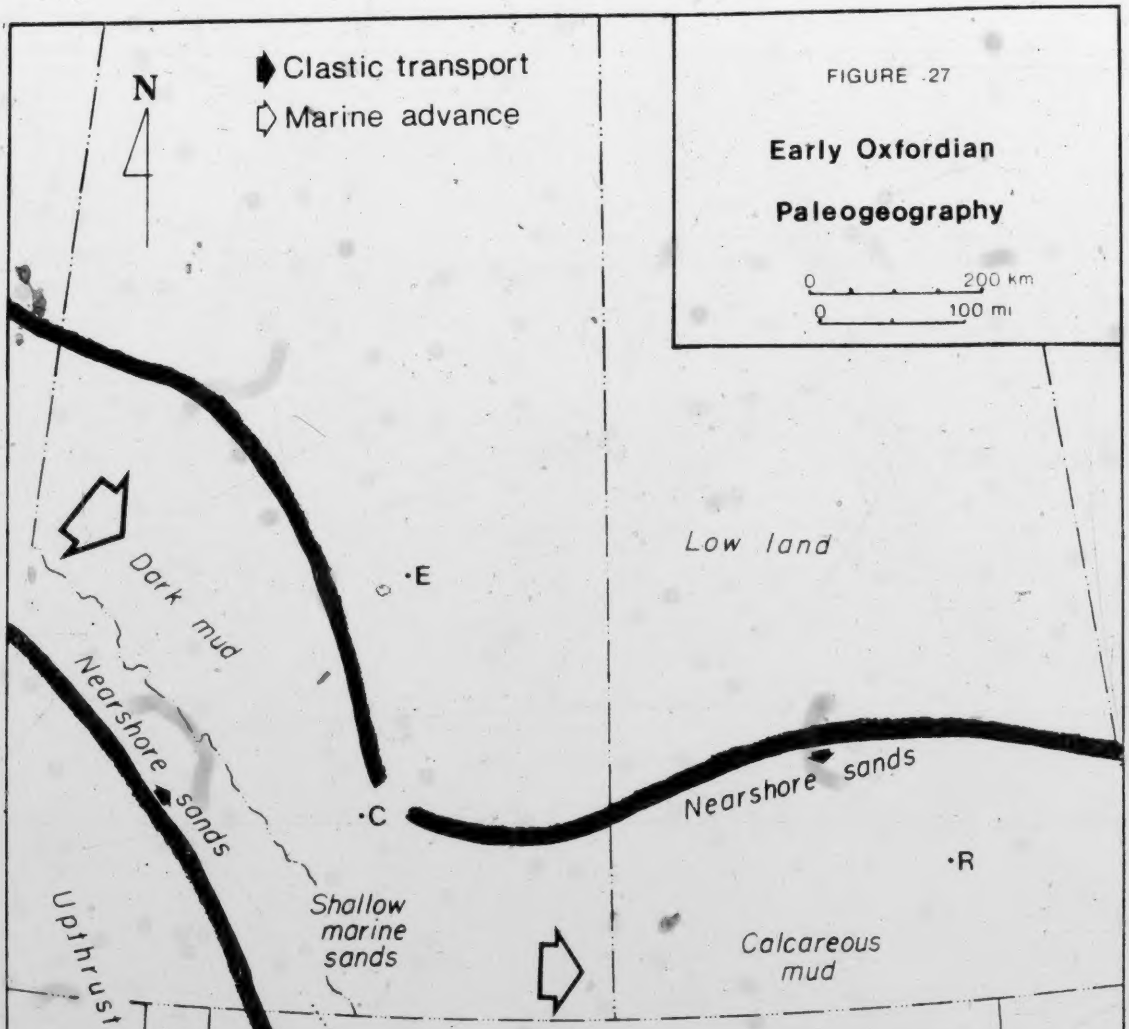


FIGURE 27

Early Oxfordian Paleogeography

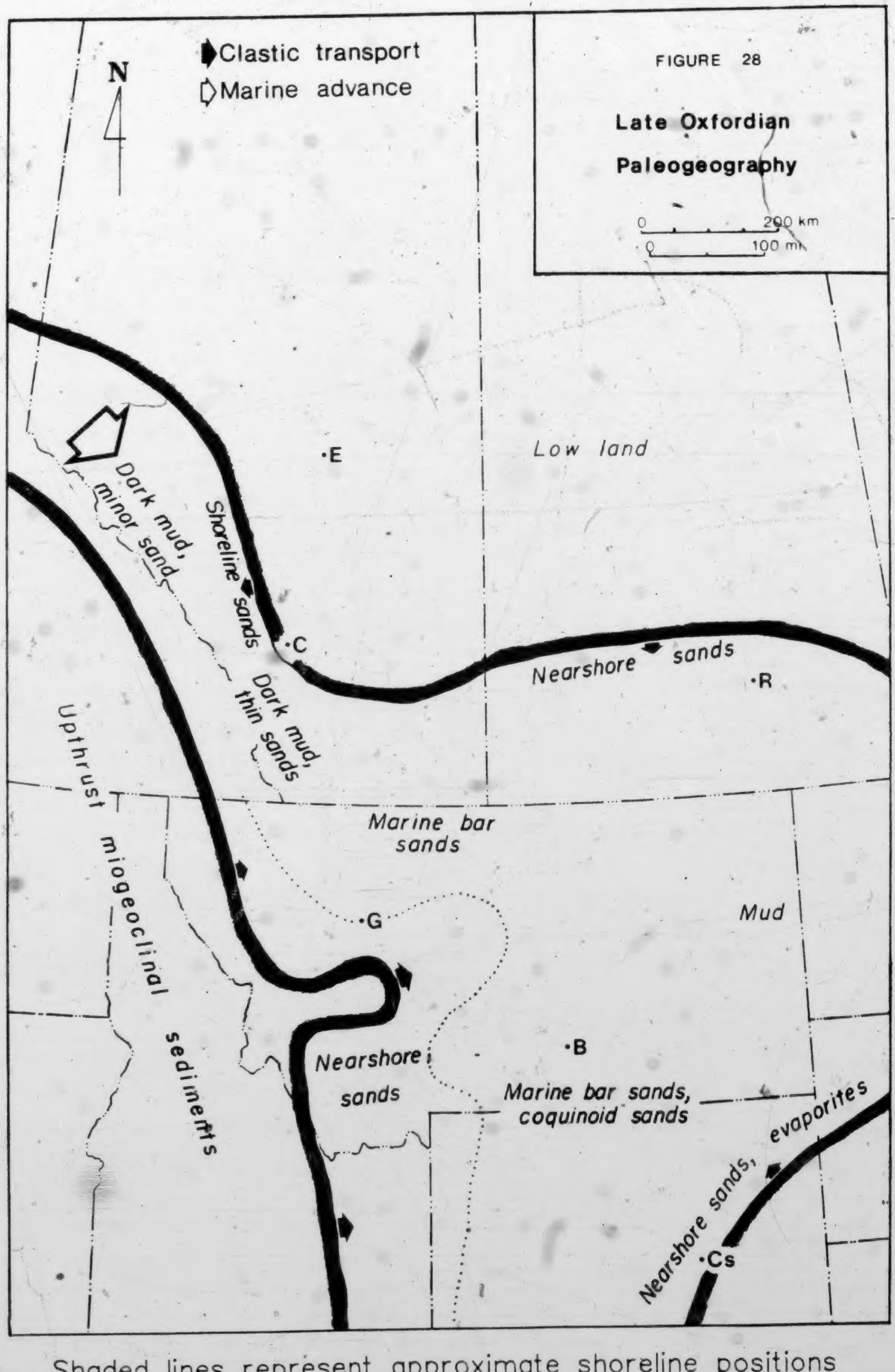
N
Clastic transport
Marine advance
0 200 km
0 100 mi
Low land
E
Dark mud
Nearshore sands
C
Nearshore sands
R
Shallow marine sands
Calcareous mud
Upthrust miogeoclinal sediments
G
Nearshore sands
Dark mud
B
Cs

Shaded lines represent approximate shoreline positions

Trough. Nearshore sands were laid down along the edge of the rising orogenic land and around the emergent part of the Belt Island trend, while mud deposition across the interior produced the dark basal shale member of the Swift Formation in southern Alberta and Montana, the basal shale of the Upper Sundance in Wyoming and the American part of the Williston Basin, and the Masefield Shale of Saskatchewan. No direct evidence of paleoshorelines is preserved in the map area, as erosion has removed Oxfordian strata for an indeterminate distance north and west of the present outcrop edge. The Sweetgrass Arch - Belt Island high continued to subside, as the basal shale of the Swift thins only slightly across the Sweetgrass Arch. Only the extreme southwestern part of the Belt Island trend was completely emergent.

Increasing clastic influx from the west caused extensive shallowing of the seaway during the late Oxfordian; Fig. 28 shows the resulting paleogeography. Nearshore sands continued to accumulate along the edge of the emerging western land mass and the Belt Island trend, and similar sand facies were probably deposited at the western edge of the Alberta Trough in southern British Columbia, but were later eroded. In the Alberta Trough, upward-increasing incidence of sandstone in the Passage beds of the Upper Fernie provides evidence of the increasing coarse clastic influx.

Over large areas of the western interior, the "marine bar-sand facies" of Brenner and Davies (1974) was deposited.


N
Clastic transport
Marine advance
FIGURE 28
Late Oxfordian
Paleogeography
0
200 km
0
100 mi
E
Low land
Dark mud, minor sand
Shoreline sands
C
Nearshore sands
R
Dark mud, thin sands
Upthrust miogeoclinal sediments
Marine bar sands
G
Mud
B
Nearshore sands
Marine bar sands, coquinoid sands
Nearshore sands, evaporites
Cs

Shaded lines represent approximate shoreline positions

Storm waves and currents transported coarse clastic debris from western source areas over the broad shelf, reworking these sediments to form the bar sand and interbar facies discussed in Chapter IV. Nearer the source areas in central and southern Montana and in coarse sandstones with abundant coquinas make up the upper sandy member of the Swift and Upper Sundance Formations. In northern and eastern Montana, Alberta, and western Saskatchewan, finer sands and silts dominate the upper member of the Swift, Upper Sundance, and "Success S1". The Sweetgrass Arch and northern Belt Island trend had little influence on the patterns of deposition, although the water was probably very shallow over the arch during the late stages of progradation. Little coarse clastic detritus reached the centre of the Williston Basin, where mud deposition continued. Sandier nearshore facies were laid down at the eastern edge of the Williston Basin, while silt, sand, and evaporite deposition characterized the areas to the south and southeast. Shoreline sands were also deposited along the northern edge of the retreating sea and the eastern edge of the Alberta Trough during the latest Oxfordian (Hopkins, 1981).

D. Latest Jurassic - Early Neocomian

Allochthonous terranes continued to move eastward toward the craton during the latest Jurassic and earliest Cretaceous, further deforming and upthrusting the thick miogeoclinal Paleozoic strata, and producing large volumes of sediment which were deposited as molasse in the foreland basin. Abundant igneous activity was associated with the movement and collision of the various allochthonous terranes, but the resulting igneous - metamorphic complexes were not yet exposed or sufficiently close to the craton to provide significant volumes of sediment. Stable detrital minerals, particularly quartz and chert, thus dominated the coarse clastic fraction of the molasse deposits during this interval.

In the southern Alberta Trough, the Kootenay Group was deposited during the latest Jurassic and earliest Cretaceous. Progradational regression continued as the marine basin was filled in from the south (Fig. 29), causing the sea to retreat completely from the southern Alberta Trough by late Berriasian time (Jeletzky, 1971). Upward-increasing sand content of the Fernie Passage beds records the transition from deep basin conditions to more proximal shelf turbidite deposition, and abundant hummocky cross-stratification in prodeltaic sediments indicates the importance of storm-aided sediment transport (Hamblin and Walker, 1979). Sandstones of the basal Kootenay Morrissey Formation were deposited in nearshore environments as deltaic, beach, and dune sand bodies (Gibson and Hughes, 1981). Strata of the overlying Mist Mountain Formation were laid down in subaerial deltaic and coastal and alluvial plain environments; abundant coal seams provide evidence for the presence of extensive back-swamp and marsh

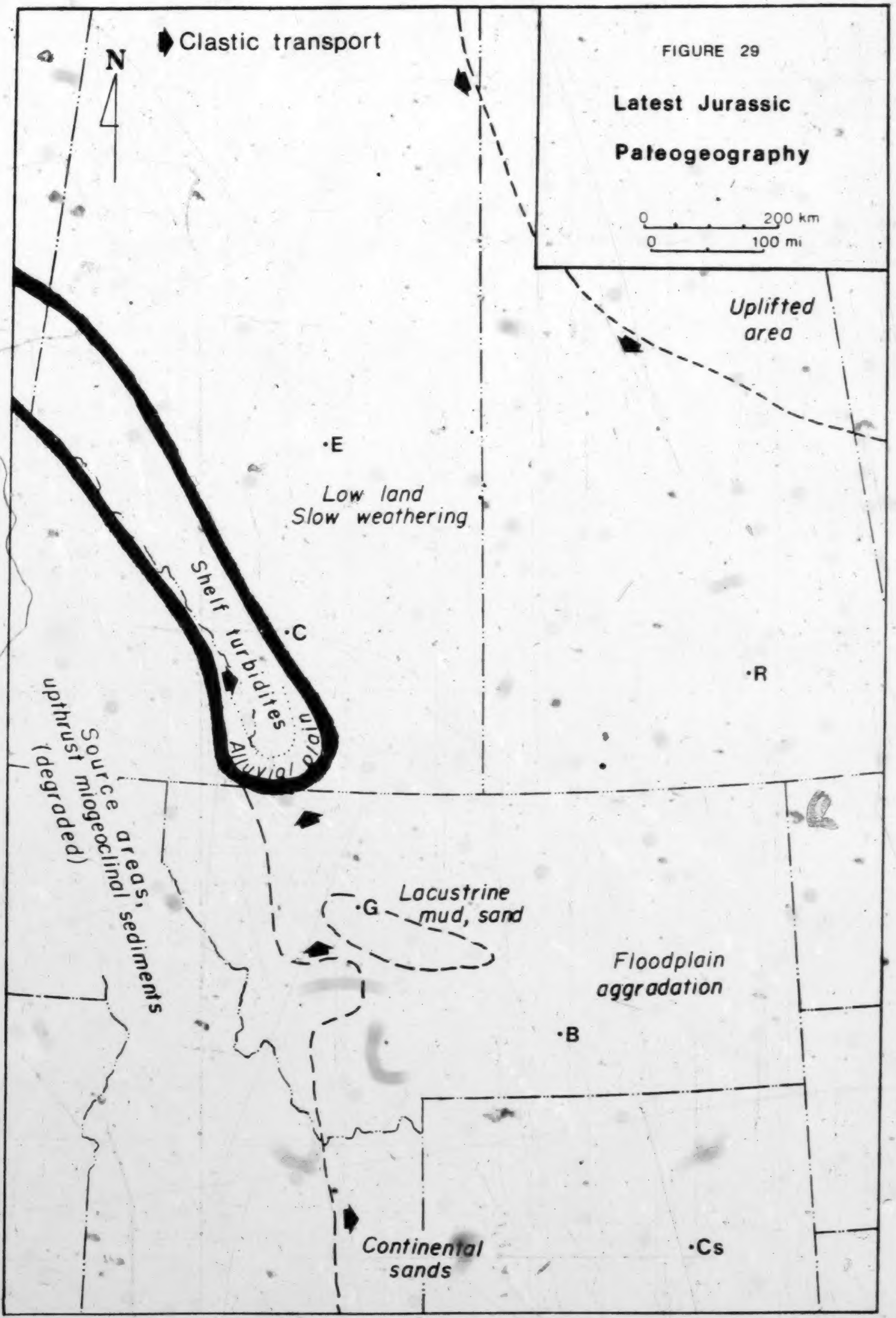


FIGURE 29

Latest Jurassic Paleogeography

Clastic transport
N
0 200 km
0 100 mi
Uplifted area
E
Low land Slow weathering
Shelf turbidites
Alluvial plain
C
R
Source areas, upthrust miogeoclinal sediments (degraded)
G
Lacustrine mud, sand
Floodplain aggradation
B
Continental sands
Cs

Shaded lines represent approximate shoreline positions

environments. Coarser sandstones and conglomerates of the Elk Formation, which were laid down in more proximal alluvial environments, complete the progradational sequence. Although the Kootenay succession is erosionally truncated to the west near Fernie, B.C., textural data and sedimentary structures indicate that the source area was fairly close by (Gibson and Hughes, 1981).

The extent and correlation of the Kootenay to the south is poorly documented, and consequently it is not clear how far the progradational environments discussed above can be traced in this direction. Immediately southeast of Great Falls, black carbonaceous shale, coal, and lenticular sandstone and siltstone occur near the top of the Morrison (Harris, 1966), facies which have been interpreted as the product of lacustrine deposition in a closed basin (Peterson, 1966). It seems more reasonable, however, to postulate some connection of this basin with the northwesterly-directed drainage system which fed into the Kootenay sea.

Across the American portion of the western interior basin, variegated mudstones, siltstones, and sandstones of the Morrison Formation were derived from the west and deposited under continental conditions during the latest Jurassic. Aggradation continued uninterrupted from late Oxfordian time, and thus the Morrison lies conformably on marine Oxfordian strata over most of the western interior. In response to the northwestward retreat of the sea, the marine - continental boundary becomes younger to the northwest. The Belt Island trend had subsided almost completely by the latest Jurassic, although Suttner (1969) showed that it was still shedding coarse clastic debris during Morrison time. Walker (1974) suggested that the Williston Basin may have been the depocentre for several systems of internal drainage, although streams which followed the course of retreat of the sea drained a substantial portion of Montana. Several workers have postulated a large influx of volcanic ash into the foreland and cratonic platform basins during Morrison time, but such an influx is of minor importance when the ash content of some of the overlying strata (eg. the Cloverly of Wyoming) is considered.

Latest Jurassic and earliest Cretaceous events in the Canadian portion of the western interior are less clear. Sufficient relief still existed on the Sweetgrass Arch to prevent any substantial amount of sedimentation. Uplift centred in the north toward the Canadian Shield caused Jurassic strata to be upturned and eroded to the south, thus destroying the record of the northern reaches of the Jurassic System. Fluvial sediments of the S2 member of the Success Formation derived from the uplifted shield were deposited over southern Saskatchewan (Christopher, 1974), while in central Alberta and Saskatchewan, the Deville Member formed as a weathering residuum over the broad, low-relief plain floored by Mississippian and Devonian carbonate bedrock. Coarse clastic debris was confined to the Alberta Trough to the west, and was thus not transported onto the cratonic platform.

Relationships among the Morrison, Success, and Deville units are unclear, but they all accumulated slowly over long periods of time during the latest Jurassic and earliest Cretaceous. Both the Deville and Success are shown in Fig. 22 to be younger than the Morrison, but it is possible that all three are largely contemporaneous.

E. Late Neocomian - Middle Aptian

A long period of stable tectonic conditions marked the Neocomian of the western interior; consequently, very slow erosion or aggradation took place over most of the area (Fig. 30). In the Canadian portion of the cratonic basin, channelling of the Mississippian and Devonian bedrock surface took place as the Deville Member and Success (S2) Formation continued to accumulate (Williams, 1963; Christopher, 1974). In most areas to the south, deposition of the Morrison Formation had effectively ceased by early Neocomian time. The Kootenay sea had retreated north along the Alberta Trough, leaving a broad alluvial plain which experienced prolonged erosion. Long-term pediment development deeply eroded the Kootenay Group on the eastern flank of the Columbian Orogen (McLean, 1977).

Tectonic activity in the western orogenic terranes increased markedly at some time during the late Neocomian.

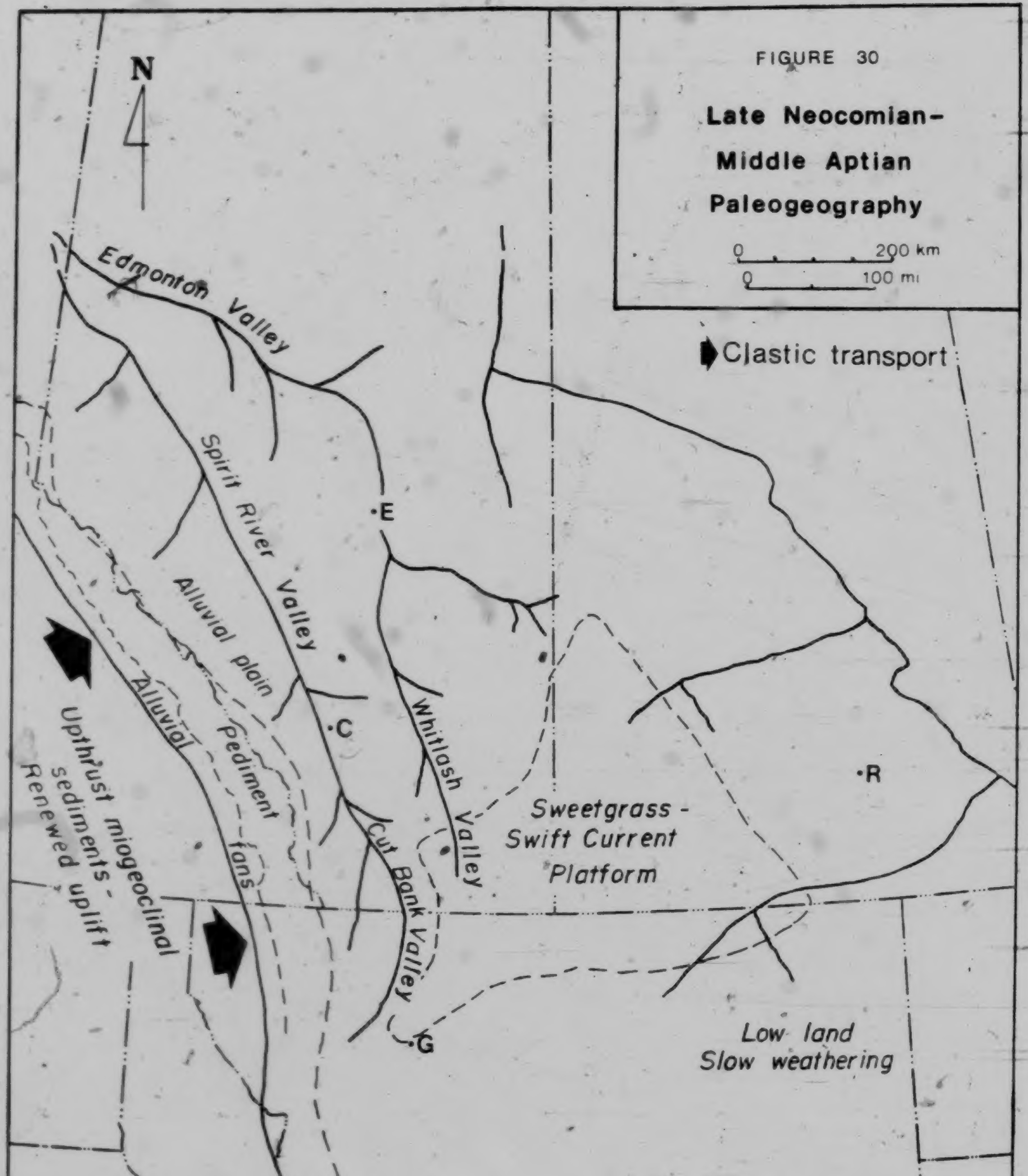


FIGURE 30

Late Neocomian-Middle Aptian Paleogeography

0 200 km
0 100 mi
Clastic transport
N
Edmonton Valley
Spirit River Valley
Whitlash Valley
Cut Bank Valley
Alluvial plain
Alluvial
Pediment fans
Upthrust miogeoclinal sediments - Renewed uplift
Sweetgrass - Swift Current Platform
Low land
Slow weathering
Floodplain deposition abundant ash
Volcanoes
E
C
G
R
B
Cs

In southern and central British Columbia, the composite allochthonous terrane I of Price _et al_. (1981) was pushed against the miogeoclinal wedge of Paleozoic strata with renewed vigour, resulting in an acceleration of the rate of uplift of source areas immediately west of the Alberta Trough. This activity may reflect the collision and suturing of composite allochthonous terrane II, another group of small land masses transported toward the continent by convergent plate motions, farther to the west. Similar events occurred at approximately the same time to the south along the Nevadan Orogen. Igneous activity also increased, as major intrusive bodies were emplaced in Idaho and British Columbia (McGookey _et al_., 1972).

Clastic influx into the foreland basin was renewed as the result of western orogenesis. At the western edge of the Alberta Trough, coarse alluvial fan sediments of the Cadomin Formation, eroded primarily from the upthrust miogeoclinal upper Paleozoic strata, overlapped the pediment gravels which continued to accumulate downslope (Schultheis and Mountjoy, 1978). In the eastern part of the trough, coarse sediments of the Cadomin and Cut Bank Formations were deposited in alluvial fans and pediments and in a northward-draining river system. A dry climate, favouring episodic depositional events, was suggested by several workers, including McLean (1977) and Schultheis and Mountjoy (1978). McLean postulated that fluvial aggradation began only after a rise of base level from early Neocomian levels, possibly as the result of the blockage of the drainage system by an alluvial fan complex. The Cadomin and Cut Bank Formations are bounded to the east by sharp valley walls, which prevented coarse detritus from reaching eastward into the cratonic basin during the late Neocomian.

Although most of the Belt Island trend remained low during the Early Cretaceous, minor uplift along the Sweetgrass and North Battleford Arches and over the adjacent Swift Current Platform helped to define a southern boundary of the Cut Bank - Spirit River drainage system (Figs. 24, 30). This uplift was the product of renewed activity along the ancestral Sweetgrass Arch trend, which in turn was probably connected with the increased western orogenic activity. Walker (1974) outlined an area in northern Montana where the basal "Kootenai" coarse clastics are absent, suggesting that this was part of the paleotectonic high. Deep channelling took place over the Sweetgrass - Swift Current Platform as it was uplifted, as exemplified by the Whitlash Valley in the thesis area and several pre-Cantuar "valley-forms" in southwestern Saskatchewan outlined by Christopher (1974, 1980).

While streams flowing from the western uplands in northern Montana were diverted to the north, streams in central Montana and further to the south drained out into the cratonic platform. Aprons of coarse clastic sediment were laid down in pediment, alluvial fan, and various fluvial environments in a fairly narrow strip along the upland flank (Stokes, 1950; Peterson, 1966; McGookey et al., 1972). These strata include the basal "Kootenai" sandstone of central and southern Montana, the Pryor Conglomerate of northern Wyoming, the Ephraim Conglomerate of southern Idaho and northern Utah, and numerous similar units to the south.

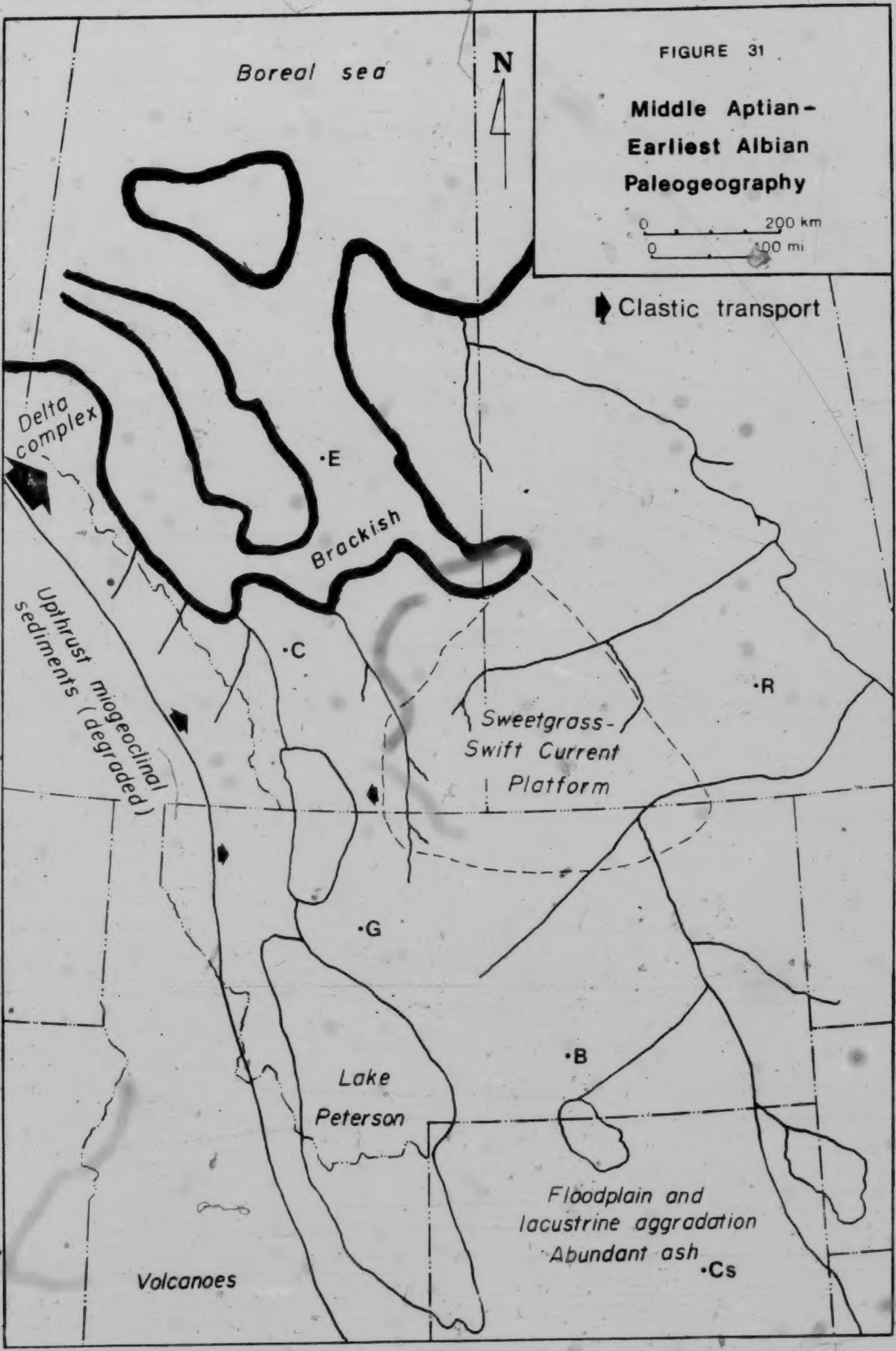
Drainage from the cratonic platform was generally toward the Boreal sea in northern Alberta and British Columbia, although several internal drainage systems may have persisted from Morrison time. The Deville Formation and possibly the S2 member of the Success Formation continued to accumulate slowly in Alberta and Saskatchewan. Little coarse detritus was deposited in the Big Horn Basin area, which was situated near the edge of the clastic apron, but thick bentonitic mudstones of the Cloverly Little Sheep Member accumulated as abundant ash derived from volcanic centres in southern Idaho was deposited.

F. Middle Aptian - Earliest Albian

By the beginning of the middle part of the Aptian stage, the western interior of North America had been subjected to a long period of erosion. A deeply channelled lowland mantled in residual weathering debris occupied much of what is now Alberta and Saskatchewan (Fig. 31). To the south, less erosion had taken place, but little aggradation had occurred in many areas.

FIGURE 31

Middle Aptian-Earliest Albian Paleogeography


Boreal sea
N
0
200 km
0
100 mi
Clastic transport
Delta complex
·E
Brackish
Upthrust miogeoclinal sediments (degraded)
·C
·R
Sweetgrass-Swift Current Platform
·G
·B
Lake Peterson
Floodplain and lacustrine aggradation
Abundant ash
·Cs
Volcanoes

Shaded lines represent approximate shoreline positions

Aggradation dominated over erosion during the middle Aptian and relatively fine clastic sediments were deposited over the entire western interior. Much of the sediment was derived from Paleozoic miogeoclinal sedimentary rocks in the western orogenic belt, where uplift continued, although probably at a reduced rate. In southern Idaho, volcanic activity continued to supply abundant ash to areas to the east.

The precise reasons for the sudden widespread deposition of fine sediment are unclear. Suttner (1969) and Walker (1974) proposed that older Paleozoic strata, characterized by pure carbonates and shales, became the primary source rocks, providing finer detritus than the more siliceous younger Paleozoic strata which were eroded earlier in the Cretaceous. The abundant presence of kaolinite and lacustrine sediments in strata south of the thesis area indicate increased vegetation and slow aggradation during the middle Aptian (Walker, 1974; Moberly, 1960). A more humid climate is therefore indicated, possibly as a result of slowed uplift and hence decreased elevation of the Columbian - Nevadan Orogen. Intrabasinal sediment sources probably became more important under humid weathering conditions. All three factors - decreased uplift, a change in source rocks, and more humid climate - probably contributed to the deposition of fine clastics.

In Montana and Wyoming, the Kootenai and Cloverly Formations were deposited, comprising variegated siltstones and mudstones deposited in floodplain environments and lenticular quartzose channel sandstones. Lacustrine strata, characterized by dark shale, coal, and calcareous sediments, accumulated over large areas. In the Cloverly Formation of the Big Horn Basin area, siliceous hardpans and nodules are products of long-term weathering in large seasonal lakes (Moberly, 1960).

Drainage on the cratonic platform trended primarily north to northwest (Fig. 31, this paper; McGookey et al., 1972; McLean, 1977; Christopher, 1980). A few major streams transected the Sweetgrass - Swift Current Platform by virtue of continuous erosion as the platform rose. Sedimentation over the platform was limited to the major valleys and their tributaries, which were filled with lenticular sandstone bodies and abundant floodplain red beds, while Jurassic and Mississippian strata were eroded from the interfluves. These valley-fill strata make up the Gladstone Formation of southern Alberta and the McCloud Member of the Cantuar Formation of southwestern Saskatchewan.

A north-facing paleoescarpment of Jurassic strata cut by numerous stream valleys marks the northern edge of the Sweetgrass - Swift Current platform. To the north, broad quartzose sand bodies and associated floodplain and lacustrine deposits were laid down by streams which migrated over large areas, restricted only slightly by broad valleys. Alluvial plain and marginal marine sandstones, deposited where river gradients dropped sharply approaching the northern sea, are dominant in central and north-central Alberta and Saskatchewan, where they are included in the Ellerslie Member of the McMurray Formation. Paleozoic sedimentary rocks and the Precambrian Shield lying to the northeast were important sediment sources.

Near the beginning of Albian time, the Boreal sea transgressed southward, extending upstream along major river valleys (Fig. 31). Widespread deposition of lacustrine and swamp facies occurred as the lower reaches of stream systems became choked with fine sediments in response to the rise of base level. In Saskatchewan, the McCloud Member of the Cantuar Formation is capped by lacustrine and coal swamp facies (Christopher, 1974). Dark calcareous muds and minor sands of the "Calcareous" member were deposited throughout Alberta over a low-relief plain dotted with lakes and swamps. Lacustrine conditions predominated for the entire post-Cut Bank, pre-Beaver Mines interval to the south along the Spirit River - Cut Bank drainage system, as the "Calcareous" member directly overlies the Cut Bank Sandstone in this area. Immediately to the east, the Sweetgrass - Swift Current Platform remained sufficiently high to shed quartzose sandstones, which were deposited in deltaic and shoreline complexes in the lake(s) to the west (Walker, 1974; Burden and Hopkins, 1981).

Depositional patterns in the American portion of the cratonic basin were not greatly affected by the transgression of the sea. In the foreland basin adjacent to the Nevadan Orogen, a large body of limestone and shale called the Peterson Limestone was deposited as the product of prolonged sedimentation in a large lake, which probably drained northward into the Cut Bank - Spirit River system (Glass and Wilkinson, 1980). The Belt Island trend therefore must have subsided completely by this time, a conclusion reached independently by Suttner (1969).

Renewed subsidence of the foreland basin at the beginning of Albian time after a long period of relative stability is suggested by the continuity of lacustrine facies along its length. Thus, little sediment from the degrading western source area was transported out into the cratonic basin at this time.

G. Early Albian

Uplift in the Columbian and Nevadan Orogens was sharply renewed and igneous activity increased markedly during the early Albian. These events may reflect further collision of allochthonous terranes with those terranes that had already accreted to the craton. As a result, large volumes of coarse clastic sediment, characterized by a high percentage of feldspars and volcanic rock fragments, were eroded and transported into the foreland and cratonic basins. Mellon (1967) postulated that volcanic detritus was derived from vents situated along the western edge of the depositional basin. Abundant low-grade metasedimentary rock fragments indicate that upthrust lower Paleozoic and Precambrian miogeoclinal strata were also being eroded.

As the western orogenic areas rose, the Boreal sea advanced southward, as shown in Fig. 32. Relief on the pre-Cretaceous unconformity remained sufficiently marked to influence the pattern of marine advance. Tongues of the sea extended up the drainage channels, and the erosional remnant of the North Battleford Arch (the northern extension of the Sweetgrass Arch) (Fig. 24) limited the spread of the sea in west-central Saskatchewan (Leung, 1976). The sudden renewed influx of large volumes of sediment, combined with marine transgression, produced a distinctive sedimentary sequence of marine shales and siltstones which make up the Clearwater Formation of central and north-central Alberta. Marginal marine and shoreline sand facies are included in the Wabiskaw Member of the Clearwater and the basal member of the Upper Mannville Formation in east-central Alberta and of the upper part of the Cantuar Formation in west-central Saskatchewan.

In the central interior, continental sediments aggraded rapidly as base level rose and the heavy clastic influx continued. Sandstone, siltstone, and mudstone were deposited in marginal marine, deltaic, and fluvial environments, making up the Upper Mannville of central Alberta, the Dimmock Creek and Atlas Members of the Cantuar in Saskatchewan, and the Beaver Mines Formation of the Foothills, southern Alberta, and northern Montana. Many

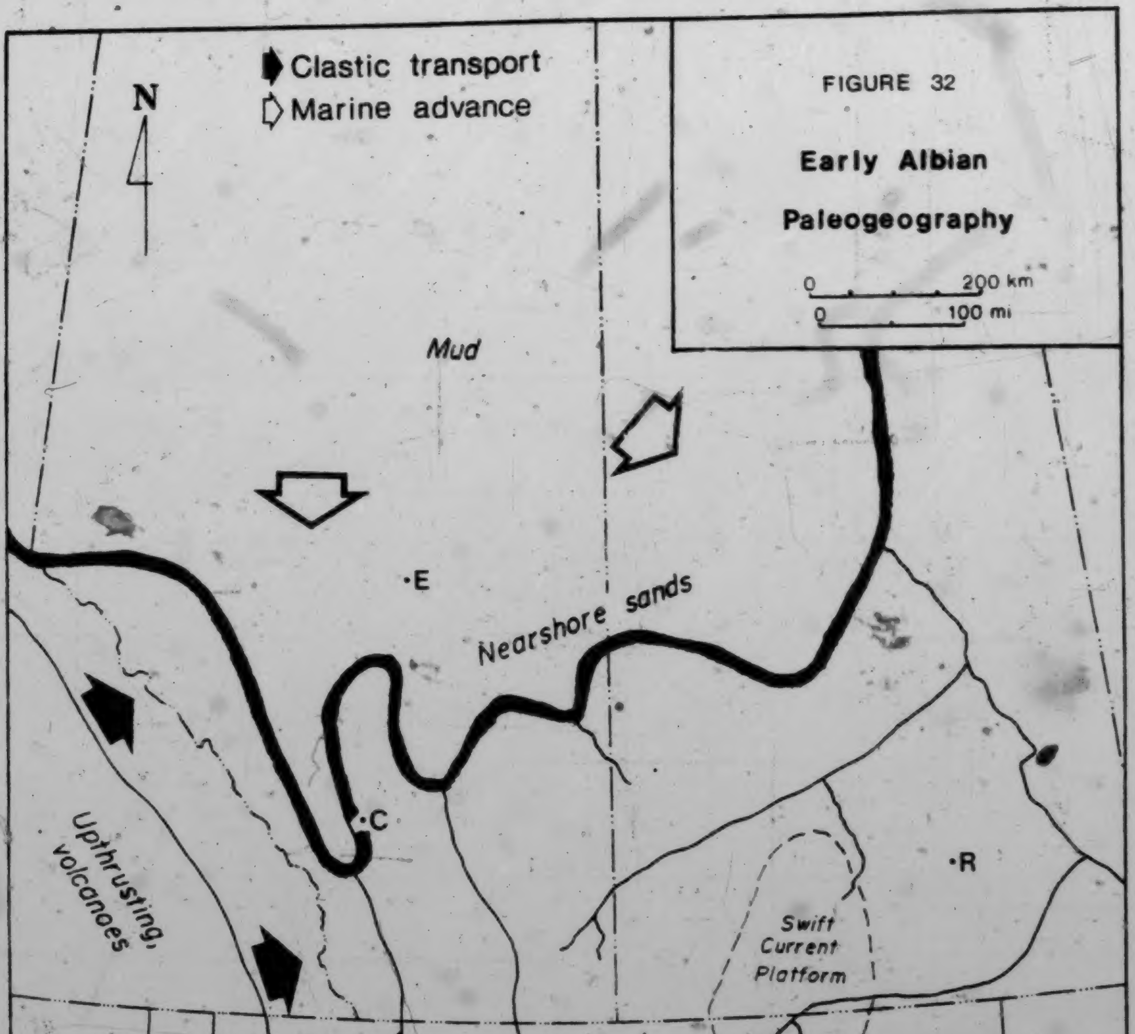


FIGURE 32

Early Albian

Paleogeography

Clastic transport
Marine advance
N
0 200 km
0 100 mi
Mud
E
Nearshore sands
C
Upthrusting, volcanoes
Swift Current Platform
R
G
B
Cs

Shaded lines represent approximate shoreline positions

lakes formed during "Calcareous" member time were filled in by prograding sand bodies. The distinctive volcanic-feldspathic lithology typifies most of the sandstones, although older sedimentary strata and the Precambrian Shield become more dominant sediment sources toward the eastern edge of the platformal basin. Sufficient sediment was deposited to fill in most of the deeply-entrenched drainage systems, although the Swift Current Platform was not completely covered until the Atlas Member was deposited (Christopher, 1974). Subsidence continued in the foreland basin as a westward-thickening wedge of sediment accumulated.

In southern Montana, Idaho, and Wyoming, the effects of uplift and transgression were less profound. In the foreland basin, the Bechler Congomerate was deposited over the Peterson Limestone in pediment, alluvial fan, and braided fluvial environments closely analogous to those in which the older Ephraim and Pryor Conglomerates were deposited. Coarse sediment was trapped so effectively in the rapidly-subsiding trough that sedimentation patterns in the east continued almost unchanged from Aptian time. In the Big Horn Basin area, slightly rejuvenated drainage caused deposition of more abundant fluvial sands in the Himes Member of the Cloverly Formation than had been deposited in the underlying Little Sheep Member.

Deposition of the Blairmore and equivalent strata marks the end of a long phase of continental sedimentation in the foreland basin, as the Blairmore is the uppermost unit of the "Lower Molasse" assemblage of Eisbacher _et al_. (1974). Sufficient progradation ultimately took place to move the Clearwater sea shoreline north again in the late early Albian. After this event, however, quiescent conditions in the western orogen and repeated transgressions resulted in the accumulation of a thick section of marine strata throughout the entire western interior during the mid-Cretaceous. Only when tectonic uplift was renewed during the Late Cretaceous Laramide Orogeny did molasse sedimentation finally fill in the entire interior basin.

VIII. PETROLEUM OCCURRENCE AND POTENTIAL

Lithostratigraphic and chronostratigraphic correlations made in this thesis have aided in constructing a regional geological history of the western interior for the Late Jurassic and Early Cretaceous. These correlations, combined with environmental interpretations, can be used to better understand and predict the occurrence of petroleum in the area.

A. History and Present Activity

Geologists realized as early as 1916 that considerable petroleum potential exists in Upper Jurassic and Lower Cretaceous strata of north-central Montana and southern Alberta. Stebinger (1916) in Montana, and Dowling *et al*. (1919) in Alberta noted that favourable structures and reservoir strata are present, but discovery and production awaited active exploration efforts.

In March of 1922, the first oil discovery was made in Sec. 16, Twp. 35N, Rge. 3W (Montana) by the Gordon Campbell - Kevin Syndicate, the well producing non-commercial amounts of oil from the basal Ellis sand (Sawtooth Formation). The first commercial well was completed in Sec. 34, Twp. 36N, Rge. 2W by the Sunburst Oil and Gas Company in June of 1922. One hundred barrels per day of medium-gravity crude were recovered from the Sunburst (basal Gladstone) sandstone (Hager, 1923). This well is considered to be the discovery well of the large Kevin - Sunburst oil and gas field, which was developed extensively over the next few decades, and continues to produce today.

Exploration activity accelerated immediately after the Kevin - Sunburst discovery. In 1926, the Cut Bank oil and gas field was discovered by the Sandpoint Berger #1 well (SENW 1 35N 5W), although development did not begin until 1931. The Sandpoint well, which recovered seven million cubic feet of gas per day from the Cut Bank Sandstone, was drilled in an effort to find a (western) downdip extension to the Kevin - Sunburst field (Blixt, 1941).

Both fields produce from numerous lenticular sandstone bodies within the lower part of the Blairmore, but even the early workers realized that the sands could not be reliably correlated between fields. Sustained wildcat drilling over the following years in both Montana and Alberta produced many discoveries of smaller fields in Mississippian, Sawtooth, Swift, Cut Bank, Gladstone, and Beaver Mines strata. Figure 33 shows the present distribution of fields producing from Upper Jurassic and Lower Cretaceous reservoirs in the study area. Most of these fields are quite small, containing fewer than ten million barrels (1.6 million cubic metres) of established oil reserves or ten billion cubic feet (280 million cubic metres) of marketable gas (Billings Geol. Society, 1958; Alberta Energy Resources Conservation Board, 1980). The Cut Bank and Kevin - Sunburst fields originally contained more than ten times

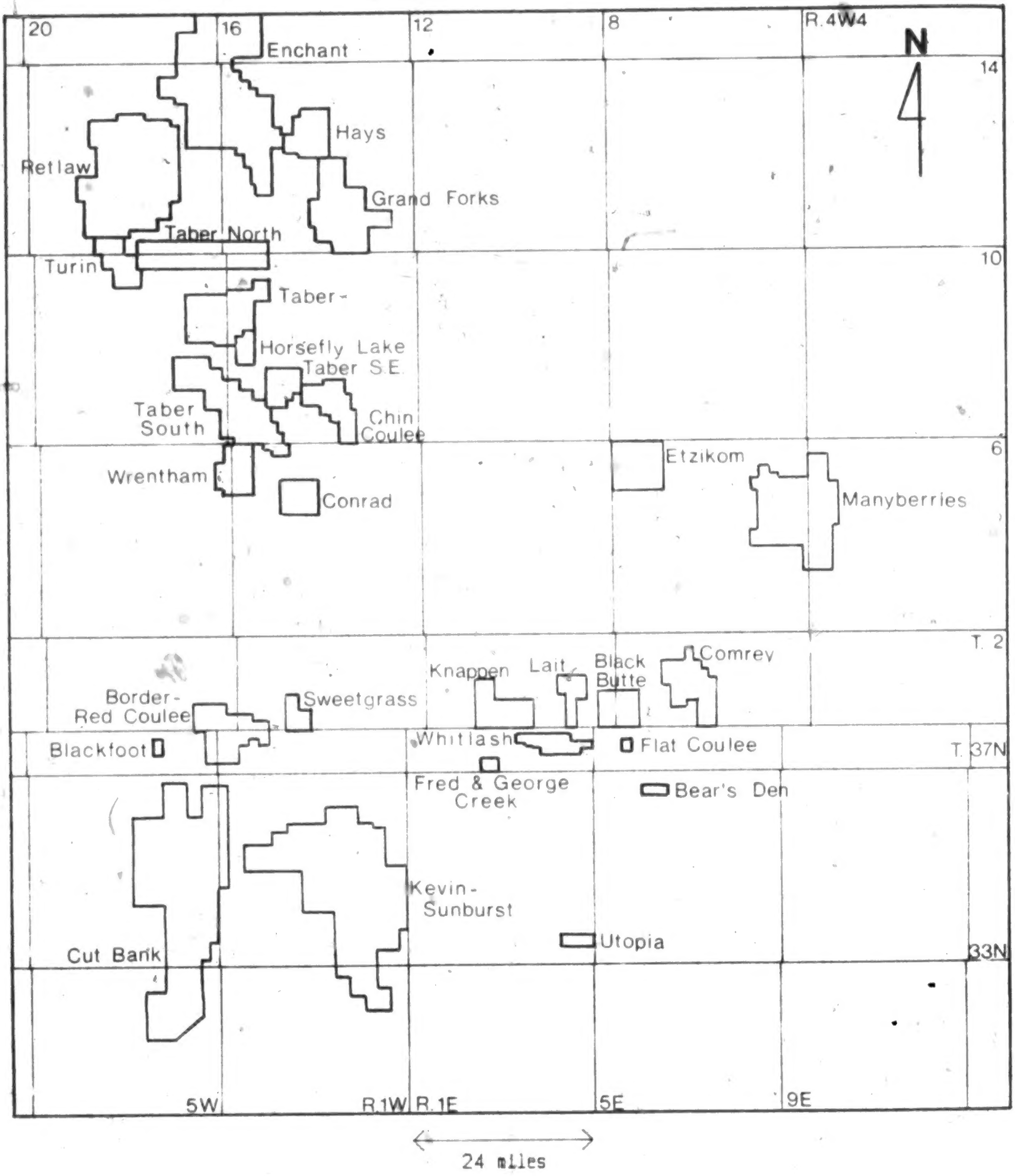

20
16
12
8
R.4W4
N
14
Enchant
Hays
Retlaw
Grand Forks
Taber North
Turin
10
Taber-
Horsefly Lake
Taber S.E.
Taber South
Chin Coulee
6
Wrentham
Conrad
Etzikom
Manyberries
T. 2
Knappen
Lait
Black Butte
Comrey
Border-Red Coulee
Sweetgrass
Whitlash
Blackfoot
Flat Coulee
T. 37N
Fred & George Creek
Bear's Den
Kevin-Sunburst
Cut Bank
Utopia
33N
5W
R.1W
R.1E
5E
9E
24 miles

Fig. 33. Oil and gas fields producing from Upper Jurassic and Lower Cretaceous strata, southeastern Alberta and north-central Montana.

these amounts, but their reserves have been greatly depleted by 50 years of production.

Petroleum exploration in the study area continues actively at the present time. In the Alberta section, 372 wells were completed to or below Lower Cretaceous and Upper Jurassic strata in 1980. Two hundred and fifty-one (67%) were classified as oil or gas wells, although some produced only from the Mississippian (Oilweek, 1980). In Montana, 94 exploratory wells and a somewhat greater number of development wells (precise breakdown not available) were drilled in 1979. Twenty-five (26%) of the exploratory wells and about 70% of the development wells were completed as oil or gas discoveries (TeSelle _et al_., 1980).

B. Occurrence of Petroleum

Petroleum has been found in every formation discussed in the thesis area except the Rierdon Shale. Trapping mechanisms are complex and diverse, involving both regional and local structural features as well as erosional and depositional stratigraphic controls.

The Kevin - Sunburst Dome is the primary regional structural feature (Fig. 5c). Its configuration has controlled the migration of petroleum to the many fields on its flanks, while numerous smaller folds radiating from its northern end are locally significant in oil entrapment (Russell and Landes, 1940; Erdmann and Schwabrow, 1941; Herbaly, 1974). Deformation of strata caused by the emplacement of the Sweetgrass Hills has affected the configuration of small fields in the immediate vicinity. Faulting has not significantly affected petroleum migration or entrapment on a regional scale.

Stratigraphic controls of petroleum entrapment fall into two categories: deposition of lenticular reservoir sandstones, and pinchout of sandstones against relief on unconformity surfaces. Both categories are illustrated in the following discussions.

The Sawtooth and Shaunavon Formations contain minor accumulations, usually of gas. They are rarely primary objectives of field development, but instead are exploited in conjunction with more productive Mississippian or Cretaceous strata. Reservoir facies are limited to an area near the trend of the ancestral Sweetgrass Arch, where beach and shallow-marine sands were deposited. In Montana, gas is produced from the Sawtooth/Shaunavon in the Kevin - Sunburst and Utopia (Twp. 33N, Rge. 4E) fields and from numerous small fields near the Sweetgrass Hills. In each case, lenticular development of porous sandy facies near the top of a nonporous carbonate - siltstone sequence is the primary trapping mechanism. In Alberta, oil is produced from the Sawtooth only at Conrad (Twps. 5-6, Rge. 15W4) and Grand Forks (Twps. 11-12, Rges. 13-14W4). The Sawtooth has been deeply eroded at both locations, a process which produced traps in remnants of the formation that are sealed by overlying impermeable Blairmore strata.

Small amounts of oil and gas are produced from the Swift Formation in a number of fields, which are also usually only exploited in conjunction with more prolific Cretaceous reservoirs. Petroleum accumulations are almost entirely stratigraphically controlled, occurring only where a sufficiently thick lenticular section of marine bar sandstone has been deposited. Numerous small fields in the Sweetgrass Hills, the Ethridge field (Twp. 33N, Rge. 4W), and the Shelby field (Twps. 32-33N, Rges. 1-2W) produce from the Swift in Montana. The Swift does not produce in Alberta, although potential reservoir facies are developed (for example) in Twp. 4, Rge. 7W4.

Many of the largest oil and gas accumulations in the study area are found in the Cut Bank Sandstone, trapped by both structural and stratigraphic mechanisms. In the large Cut Bank field, oil migrated up the regional dip on the west flank of the Kevin - Sunburst Dome, and was trapped where the Cut Bank Sandstone pinches out against impermeable Swift strata making up the eastern escarpment of the Cut Bank Valley. Fine-grained floodplain and lacustrine facies of the Gladstone Formation provide the upper seal. A similar trapping mechanism operated at the Border - Red Coulee and Darling pools immediately to the north. In the Taber (Alberta) area (Twps. 7-10, Rges. 15-17W4), where numerous small fields produce from the Cut Bank Sandstone, the regional dip is almost directly north (Fig. 5c). Because the Cut Bank Formation is so uniformly porous and permeable, much of the petroleum which may have originally been present in this area has migrated south toward the Kevin - Sunburst culmination, finally being trapped in the Cut Bank field. North of the international boundary, oil and small amounts of gas were trapped primarily in south- to east-trending breaks in the face of the eastern escarpment. Small folds and faults are also important in the configuration of these traps (Russell and Landes, 1940). Overlying and possibly some equivalent fine continental facies form the upper seals.

The Gladstone Formation contains most of the rest of the important petroleum reservoirs in the study area. Almost all the Gladstone fields produce from lenticular sandstones which fill valleys cut into the Swift Current - Sweetgrass Platform. Some production around Twps. 36-37N, Rges. 4-6W (Montana) is from the Moulton member, which comprises shoreline sand bodies deposited around lakes in which "Calcareous" member strata accumulated. Almost every trap in the Gladstone can be attributed to the pinchout of porous sandstone against impermeable valley walls and/or within contemporaneous fine-grained sediment. Most of the fields shown in Fig. 33 east of the Cut Bank Valley produce at least some oil and gas from the Gladstone. Especially notable is the large Kevin - Sunburst field, made up of numerous small pools in channel sandstones on the western flank of the Kevin - Sunburst Dome, and the Grand Forks field (Twps. 11-12, Rges. 13-14W4 (Alberta)), which produces primarily from a Gladstone sandstone filling valleys cut into the northern edge of the Swift Current - Sweetgrass Platform.

Beaver Mines strata have not been studied in sufficient detail in this thesis to warrant an analysis of petroleum occurrence. In the thesis area, the Retlaw (Twps. 11-13, Rges. 18-19W4), Enchant (Twps. 12-15, Rges. 15-17W4), and Turin (Twps. 10-11, Rges. 18-19W4) fields all produce from the "Glauconitic" sandstone of the basal Beaver Mines Formation.

C. Future Petroleum Exploration

Much petroleum remains to be discovered in the Upper Jurassic and Lower Cretaceous strata of the study area. It is clear that individual future finds will be modest in size, although aggregate reserves may be quite respectable. Sufficient borehole data now exist to support detailed regional investigations of the depositional and erosional controls on the distribution of each formation, which can provide very valuable background data for local evaluations. Only with their aid can a geologist fully assess the petroleum potential of a particular parcel of land. Some suggestions for regional evaluations are given below.

Petroleum in the Sawtooth and Shaunavon Formations is found in lenticular sandstone reservoirs which were deposited in shallow marine and beach environments. The first step in regional evaluation is the construction of a detailed lithofacies map to outline areas containing potential reservoir facies. A detailed isopach map would elucidate the paleotopography of the Mississippian erosional surface, thus pinpointing, for example, pinchouts and possible beach sand accumulations. Also important would be an evaluation of diagenetic controls on porosity and permeability of the sandstones, which appear to be significant factors controlling petroleum entrapment in several fields.

A detailed regional study of depositional parameters controlling the trend, size, and shape of potentially productive lenticular sandstone bodies would greatly enhance evaluation of petroleum production in the Swift Formation. An investigation utilizing all the well control available could build on the general model of marine bar sand deposition, attributing preferred sand bar configurations to specific paleocurrent directions and to the influence of the ancestral Sweetgrass Arch.

Locating potential reservoir strata in the Cut Bank Formation is not difficult, but finding traps is a major challenge. A detailed map of the paleotopography of the eastern edge of the Cut Bank Valley and the immediately adjacent valley and highland areas might help to pinpoint breaks in the valley wall and therefore potential traps.

A reconstruction of the paleodrainage patterns on the eroded Swift Current - Sweetgrass Platform would be invaluable in providing a basis for the evaluation of the characteristics of possible valley-fill sandstone reservoirs in the Gladstone Formation. Paleotopographic reconstructions such as those outlined by Branch (1976) for the Fred and George Creek field (Fig. 33) and by Berry (1974) for the Grand Forks field are useful for interpreting paleodrainage trends. Such maps are difficult to draw for larger areas, however, because there are no reliable regional stratigraphic markers near the Jurassic - Cretaceous unconformity (note the use of the Fish Scales zone as a stratigraphic marker in this thesis).

In summary, regional geologic studies of potential producing strata can provide an invaluable framework upon which local evaluations can be constructed. Geophysical methods, particularly seismic, provide valuable additional data, although the thinness and lenticular nature of most of the potential reservoirs severely limit the applicability of geophysical techniques. In the final analysis, only very intensive drilling will fully evaluate petroleum prospects.

IX. SUMMARY

Southern Alberta and north-central Montana are critical to the interpretation of Late Jurassic and Early Cretaceous stratigraphy in the western interior of North America. This area straddles the north - south trending Sweetgrass Arch, from which strata dip westward toward the Alberta Syncline and eastward toward the Williston Basin. Equally important from the viewpoint of stratigraphic nomenclature is the Canada - United States border, which runs east - west through the centre of the study area. In this thesis, the Upper Jurassic and Lower Cretaceous lithostratigraphy was interpreted and refined using lithological and paleontological data from drill cores and geophysical log data. This lithostratigraphic scheme was integrated with schemes from surrounding areas to provide a unified interpretation of the Late Jurassic and Early Cretaceous geological history over the entire western interior.

Marine sedimentation commenced in the study area in the Middle Jurassic after a prolonged period of erosion. Shallow to marginal marine sandstone, siltstone, shale, and limestone of the Sawtooth and Shaunavon Formations were deposited and subsequently partly eroded, leaving an erosional surface of moderate relief underlain by Mississippian carbonates and Middle Jurassic clastic and carbonate strata.

Early Callovian strata comprise widespread homogeneous shallow marine calcareous and non-calcareous shales of the Rierdon Formation. Minor erosion occurred during the late Callovian as the sea regressed, although a substantial part of the formation was removed over the Sweetgrass Arch. During the early Oxfordian, the transgressive basal dark shale member of the Swift Formation was deposited. As the sea began to retreat, silt- and sand-sized detritus was transported from source areas to the west into the study area by storm currents, and was deposited along with dark mud in marine bar and interbar facies of the ribbon sand member of the Swift. Erosion took place from late Oxfordian through latest Neocomian time, resulting in deep channelling of the Jurassic strata.

Basal Cretaceous strata of the study area are included in the Blairmore Group because the r lithologies compare more closely with those of the Blairmore Group of the Foothills than with those of the Mannville Group, which is defined in the central Plains of Alberta. Siliceous sandstones and conglomerates of the Cut Bank Formation were deposited in streams occupying the westerly Cut Bank Valley during Neocomian (?) and early Aptian time. Finer fluvial sands and floodplain facies of the Gladstone Formation were laid down over the entire area during the Aptian, and are overlain by earliest Albian lacustrine dark shale, limestone, and sandstone of the "Calareous" member. Continental sandstones of the Beaver Mines Formation, characterized by sandstones containing abundant feldspar and volcanic debris, cap the succession.

Marine Jurassic strata in the study area can readily be correlated to the west, south, and east, but have been removed by pre-Cretaceous erosion near the northern edge of the thesis area. The first major marine advance onto the craton in the Middle Jurassic can be traced over large areas, but poor water circulation and widespread marginal marine to evaporitic conditions prevailed, as indicated by the presence of red bed and evaporite lithologies to the south and east of the study area.

More open marine conditions prevailed during the early Callovian advance, as strata of the Rierdon Formation were laid down over southern Alberta, most of Montana, and the western Williston Basin. Equivalent strata include the Lower Sundance Formation of the northern and central Great Plains, the Rush Lake Shale and Roseray Sandstone of south-central Saskatchewan, and the Grey beds member of the Fernie Formation in the southern Alberta Foothills. All of these units indicate deposition of muds over a broad shallow shelf area. Some evidence of coarser shoreline and regressive facies are found in the Lower Sundance of northern Wyoming and the Roseray of Saskatchewan.

An even more extensive marine transgression during the early Oxfordian is recorded by widespread dark shales which make up the basal Swift Formation in southern Alberta and Montana, the lower part of the Upper Sundance Formation to the south and east, the Masefield Shale in Saskatchewan, and part of the Green beds member of the Fernie in the southern Alberta Foothills. The marine bar sand facies deposited during the subsequent regression in the Swift can be traced southward through Montana and into the upper part of the Upper Sundance further to the south and east, and eastward into the "S1" unit of the Success Formation. Uplift of sources areas to the west is recorded by coarse nearshore facies in western Montana and a coarsening-upward succession in the Passage beds of the Fernie in the Alberta Foothills.

Continental strata of the Morrison Formation grade upward from the marine Oxfordian, and continued to accumulate over the American portion of the western interior during the latest Jurassic. Erosion took place to the north and continued over the entire cratonic basin during the earliest Cretaceous, producing residual weathering deposits of the Deville Member of the Mannville Group in central Alberta, and the "S2" unit of the Success Formation in Saskatchewan. Prograding shallow marine to fluvial facies of the Kootenay Group were deposited in the Alberta Trough at the same time.

Renewed uplift of western source areas triggered deposition of coarse clastics along the western edge of the craton in pediment, alluvial fan, and fluvial environments, beginning about the latest Neocomian. These sediments are included in the Cut Bank Formation in northern Montana and southern Alberta, the Cadomin Formation of the Alberta

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Foothills, and the Pryor and Ephraim Conglomerates in Wyoming and Idaho. Generally finer continental sediments were deposited somewhat later as the source areas degraded, different source lithologies were exposed, and the climate became more humid. These include the Gladstone Formation in southern Alberta and northern Montana, the Cloverly Formation in Wyoming, the McCloud Member of the Cantuar Formation in Saskatchewan, and the McMurray Formation and Lower Mannville Formation of central Alberta. Widespread lacustrine to marginal marine deposits are evident at the top of most of these units, signifying a rise in regional base level.

The stratigraphic sequence discussed in this thesis is capped by sediments deposited in continental to marginal marine environments which became more marine in character northward toward the advancing Boreal sea. Renewed uplift to the west, probably caused by increased interactions of allochthonous terranes at the western edge of the craton, caused igneous rocks to be exposed and eroded, resulting in a fairly sharp influx of feldspathic and volcanic sediments into the cratonic and foreland basins. These strata are included in the Beaver Mines Formation in southern Alberta and northern Montana, the Cloverly Formation to the south, the Dimmock Creek and Atlas Members of the Cantuar Formation in Saskatchewan, and the Upper Mannville and Clearwater Formations in central and northern Alberta.

Considerable reserves of petroleum are trapped in Upper Jurassic and Lower Cretaceous strata in southern Alberta and north-central Montana, but extensive drilling is needed to discover and exploit the numerous small reservoirs. Studies which may aid in exploration strategies include: determining regional depositional patterns to aid in prediction of sand bar geometries and orientations in the Swift Formation; mapping erosional breaks in the eastern wall of the Cut Bank Valley, where petroleum might be trapped in the Cut Bank Sandstone; and mapping Early Cretaceous paleodrainage patterns which controlled deposition of lenticular sandstones of the Gladstone Formation.

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EXPLANATION OF PLATE 1

A. McColl - Frontenac Union 9A-22 (9-22-3-8W4)
2920 feet

Chert pebble - belemnite conglomerate, base of shale member of Swift Formation. (Scale bars are 1 cm. long).

B. CMG Pan Am Pendor (11-35-2-9W4)
2721 feet

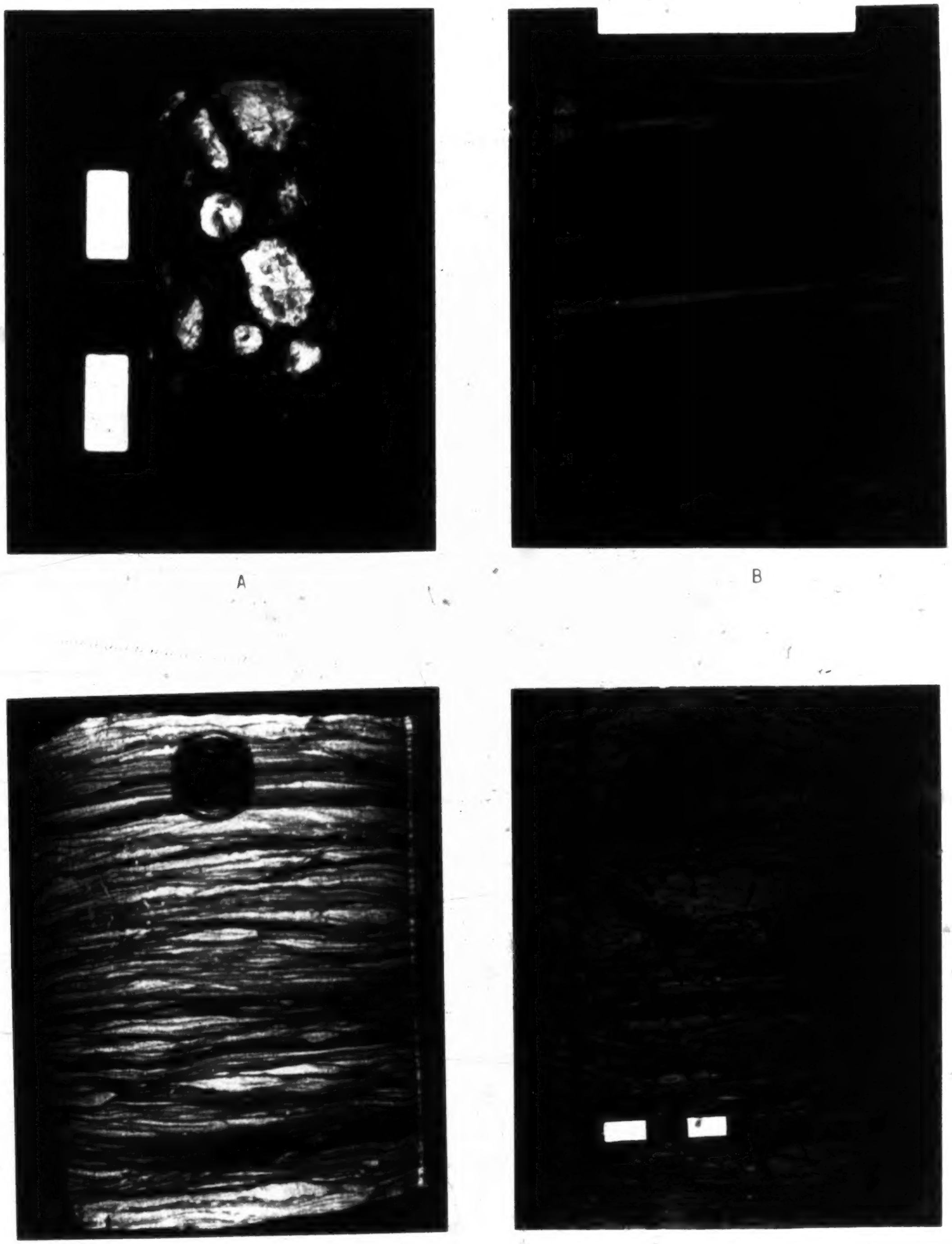
Typical development of dark-coloured, lenticularly-bedded ribbon sand member of Swift Formation, showing silt streaks and siltstone lenses in dark shale. Small light-coloured spots are truncated _Chondrites_ burrows. (White scale card is 5 cm. long).

C. CMG Aden (6-31-1-10W4)
2822 feet

Typical development of light-coloured ribbon sand member of Swift Formation, showing lenticularly-bedded coarse siltstone in a finer matrix, with most mud-sized material confined to thin wavy beds between siltier beds. (Dime for scale).

D. CMG Cypress (6-23-7-3W4)
4676 feet

Dark ribbon sand displaying moderate bioturbation. Original silt-streaked to lenticular bedding is still distinguishable, but most sand lenses are cut by mud-filled burrows, while sand-filled burrows are common in mudstone beds. Note large pyrite nodule. (Scale bars are 1 cm. long).



A B

C D

PLATE 1.

EXPLANATION OF PLATE 2

A. CMG Black Butte (5-17-1-8W4)
2962 feet
Dark ribbon sand showing predominantly wavy bedding; note presence of both siltstone and cherty medium-grained sandstone lenses. Reactivation surfaces with thin mud drapes are common in the siltstone lenses, signifying variable wave and current energies. This core was taken near the Flat Coulee oil field, where oil is produced from 12- to 15-foot beds of sandstone in the Swift. (Scale bars are 1 cm. long).

B. CMG Pan Am Pendor (7-29-2-8W4)
2806 feet
Dark ribbon sand displaying well-defined alternation between cross-bedded fine sandstone beds and silt-streaked mudstone beds. Reactivation surfaces and mud drapes are common in the sandstone beds. This is a very clear example of the alternation of wave and current energies which occurred during deposition of the ribbon sand. (Scale card is 5 cm. long).

C. CMG Pakowki (6-2-4-7W4)
2900 feet
Dark ribbon sand composed of small-scale trough cross-bedded sandstone, with only isolated flasers of muddy material. (Scale bars are 1 cm. long).

D. Decalta Altair Milk River (2-4-1-17W4)
2778 feet
Cut Bank Sandstone, showing typical development of large-scale planar cross-bedding. The lower sequence is truncated and overlain by a thin pebble layer and then another planar cross-bedded sequence. (Scale card is 5 cm. long).

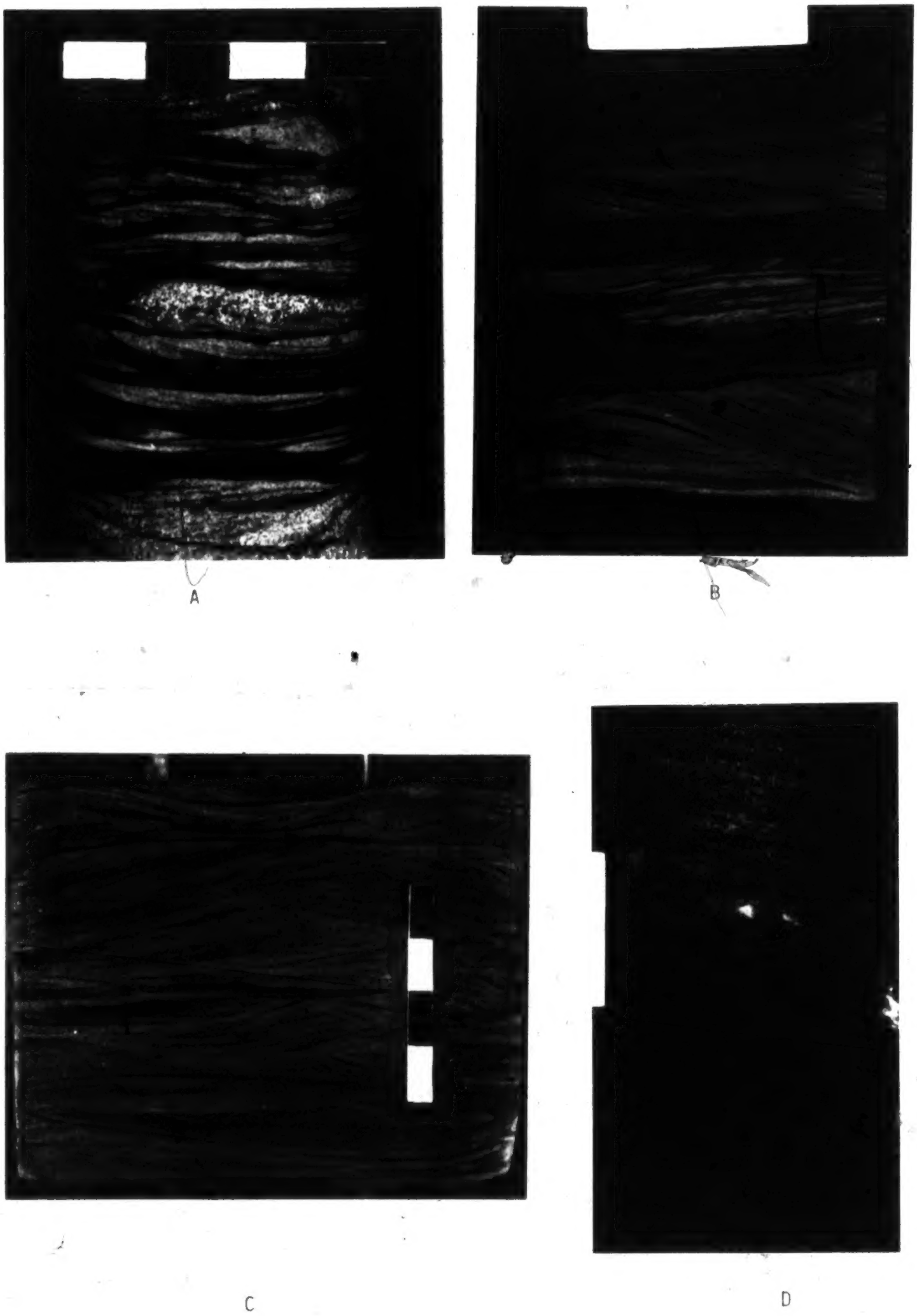


PLATE 2.

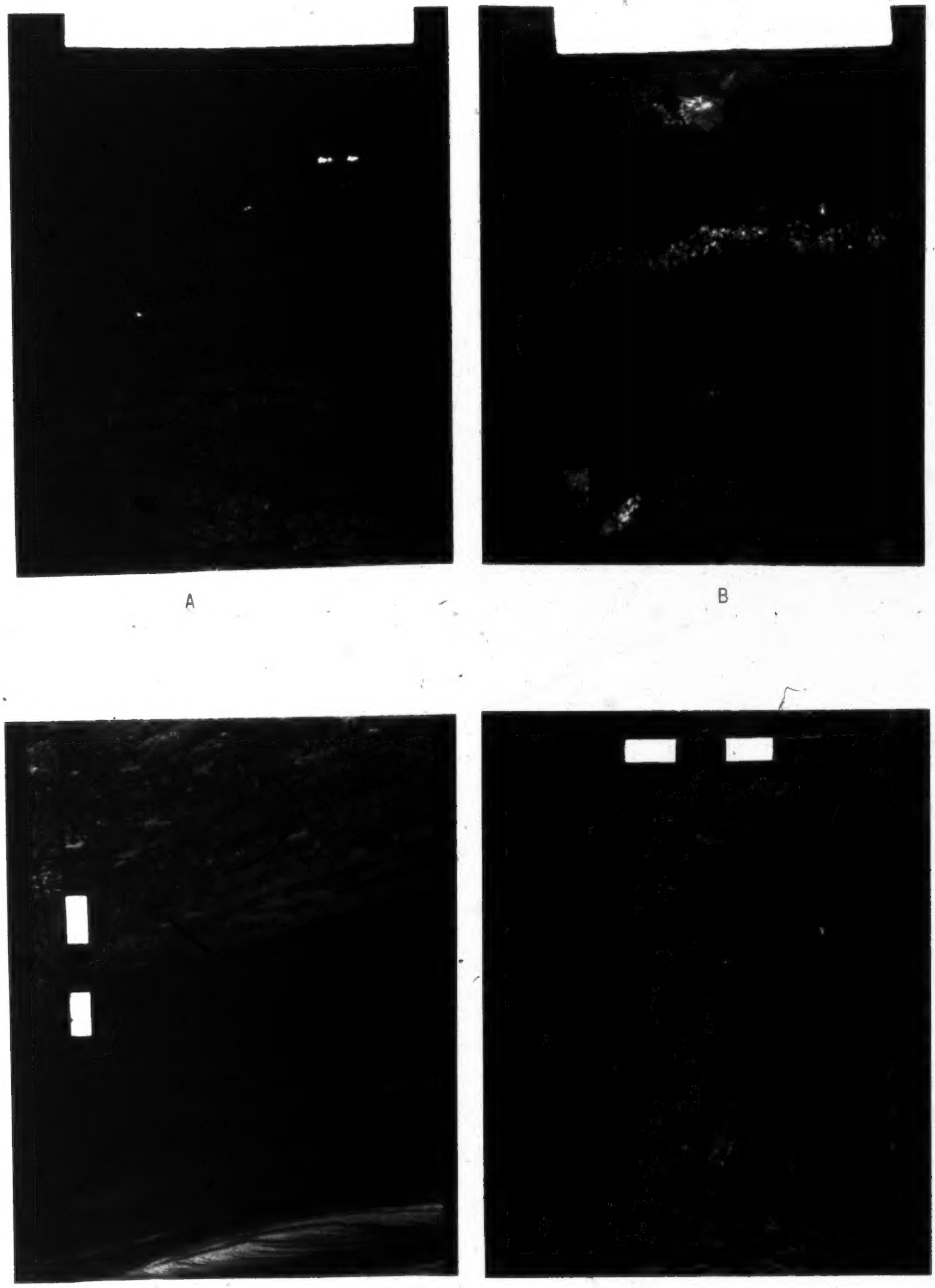
EXPLANATION OF PLATE 3

A. Decalta Altair Milk River (2-4-1-17W4)
2760 feet
Cut Bank Sandstone, containing plastically-deformed mud clasts suspended in medium-grained litharenite. (Scale card is 5 cm. long).

B. Decalta Altair Milk River (2-4-1-17W4)
2797 feet
Cut Bank Sandstone - conglomerate bed near base. Pebbles are primarily chert with some argillite. Note also the large coal fragment in the centre of the photo. (Scale card is 5 cm. long).

C. CMG Pendor (10-20-3-7W4)
2888 feet
Sharp contact of basal Gladstone sandstone over ribbon sand member of the Swift Formation. Note the abundant mud clasts in the coarse-grained chert-rich sandstone. (Scale bars are 1 cm. long).

D. TNR Omega Comrey (10-27-2-5W4)
3175.5 feet
Gladstone Formation - grey-green, poorly-sorted silty mudstone, showing abundant root traces. (Scale bars are 1 cm. long).



A B

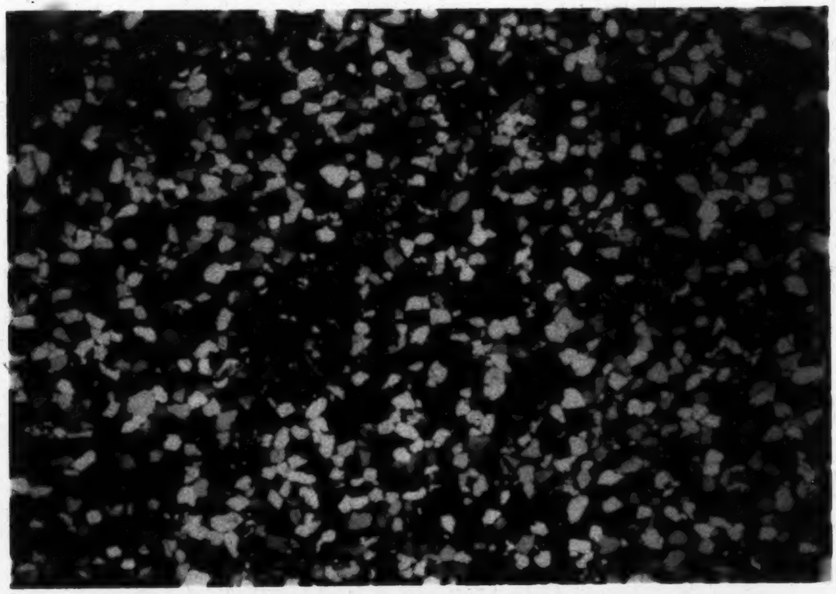
C D

PLATE 3.

EXPLANATION OF PLATE 4

A. CMG Black Butte (5-17-1-8W4)
   2943 feet
      Dark ribbon sandstone - photomicrograph of fine sublitharenite, composed almost entirely of quartz and chert. (Fully-crossed nicols, field width 10.5 mm.).

B. Westcoast Twin River (14-33-1-19W4)
   3545.5 feet
      Cut Bank Sandstone - photomicrograph of basal lithic paraconglomerate. Almost all pebbles are composed o[illegible] chert with variable staining; some show a number of inclusions. Matrix is composed of fine- to medium-grained sublitharenite cemented by silica, and with good intergranular porosity. (Fully-crossed nicols, field width 10.5 mm.).



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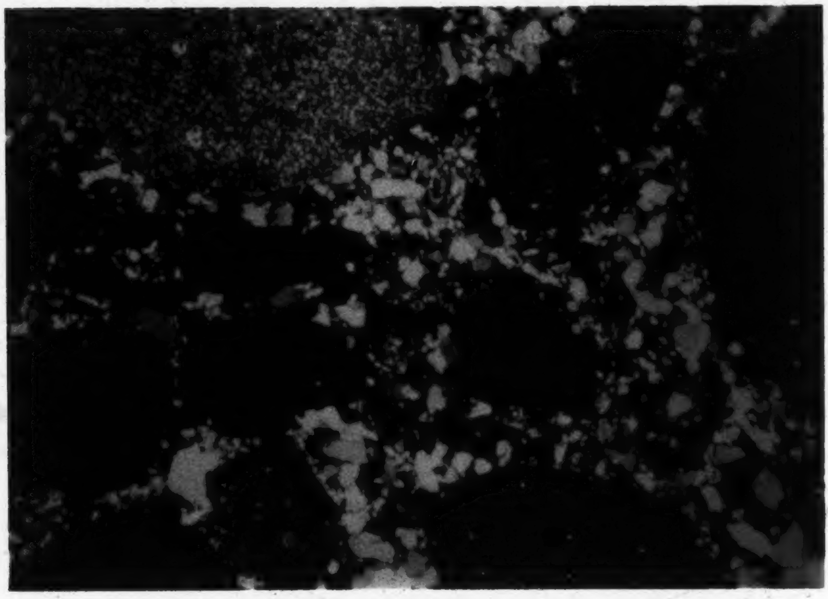

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PLATE 4.

EXPLANATION OF PLATE 5

A. CPOG Horsefly Lake (12-20-8-16W4)
3197.5 feet
Cut Bank Sandstone - photomicrograph of medium-grained calcareous litharenite. Grain composition is very typical of the Cut Bank, although the amount of calcite cement is unusually high. (Fully-crossed nicols, field width 10.5 mm.).

B. CMG et al Pendor (6-1-4-9W4)
2853 feet
Gladstone Formation - photomicrograph of typical basal submature litharenite. The grains are predominantly quartz and chert, although there are some sedimentary rock fragments. (Fully-crossed nicols, field width 10.5 mm.).

A

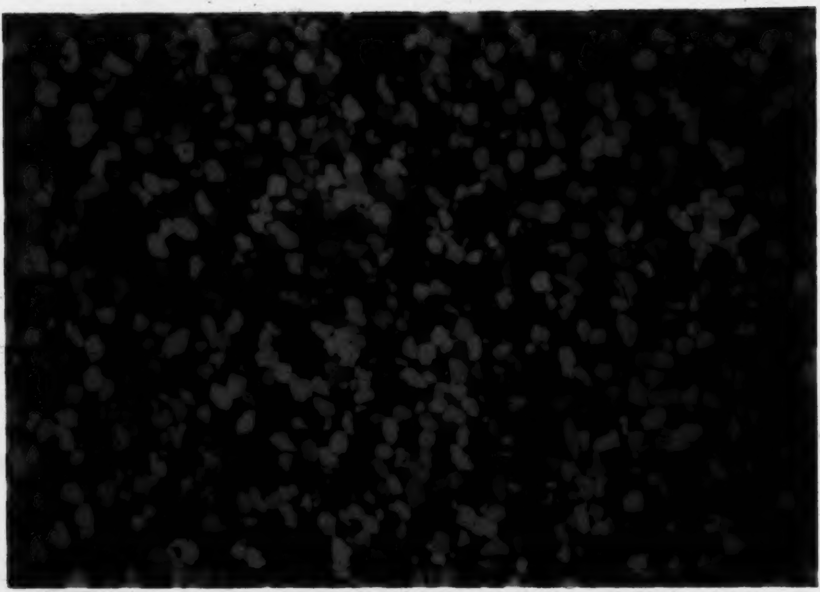
B

PLATE 5.

EXPLANATION OF PLATE 6

A. Gridoil Teck Hays (16-28-13-14W4)
3124.5 feet
Gladstone Formation - photomicrograph of supermature lithic quartzarenite. Very well-sorted, cemented entirely by silica, and contains an unusually high percentage of heavy minerals. (Fully-crossed nicols, field width 10.5 mm.).

B. Shell Manyberries (6-23-6-7W4)
957.9 metres (3143 feet)
Beaver Mines Formation - photomicrograph of submature feldspathic extralitharenite. Contains about 20% quartz, 10% variably-weathered feldspar, and 70% chert and volcanic rock fragments. Also present are detrital carbonate grains, dark micas, and plant debris. (Fully-crossed nicols, field width 10.5 mm.).



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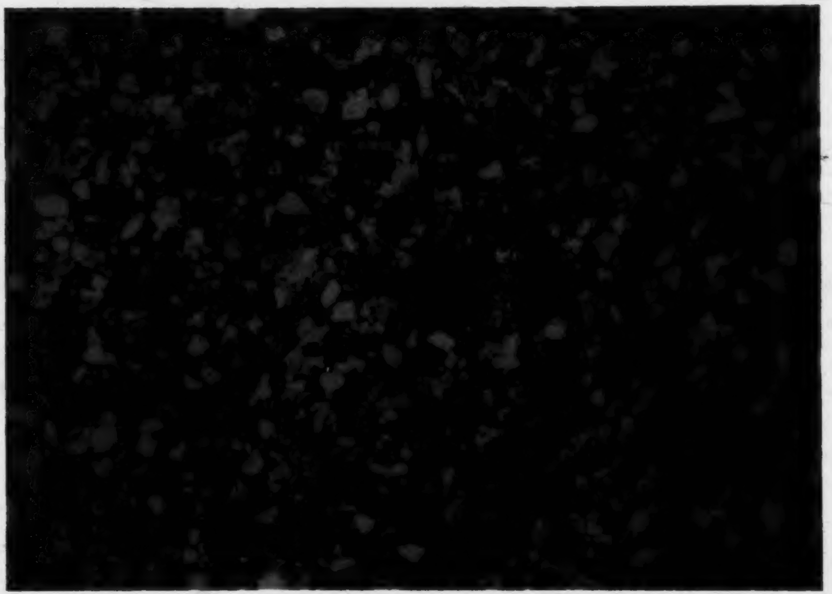

B

PLATE 6.

APPENDIX A

Core Descriptions

This appendix presents descriptions of many of the cores examined for this thesis. The descriptions are brief and are intended primarily to establish the dominant lithologies for the purpose of stratigraphic correlation. The notes below are important for the use of this appendix.

Depths listed on cores are often significantly different than depths plotted on geophysical logs. Care must be taken to observe the sequences of lithologies and log responses in order to correlate the depth scales.

Sandstone classification follows Chen (1968) (see text - Fig. 4).

The use of the term "ribbon sand" implies a group of lithologies in the Swift Formation described completely in Chapter IV. Descriptions made in association with the term in this appendix serve only as modifiers.

Palynological analyses were performed by both S.A.J. Pocock of Esso Canada Resources and A.P. Audretsch of Shell Canada Resources. Where their interpretations of a particular palynomorph assemblage do not agree, both interpretations are listed, and the author of each is indicated by his initials. "No flora/fauna recovered" implies that the interval was sampled but that no fossils were found. Finally, the term "DRS flora" is used to signify a palynomorph assemblage found by A.P. Audretsch to be consistently associated with the dark-coloured ribbon sand member of the Swift Formation.

Miami Oil TMCBSU #33-16
SWSW 33 32N 6W
KB 3642; TD 3286
3180-3224 feet

FOOTAGE	FORMATION	DESCRIPTION
3180-3183	Gladstone	Mudstone, silty, dark maroon with green mottling. Some floating sand grains.
3183-3191		Siltstone, grey-green, waxy. Fining-up; argillaceous at top, arenaceous at base. Minor carbonaceous debris.
3191-3202		Sandstone, silty to fine, submature litharenite. Variably calcareous, some siderite. Thin sets of well-developed small-scale trough cross bedding, especially near base. Indistinct basal contact.
3202-3204.5	Cut Bank	Sandstone, fine to medium, litharenite. Low-angle planar cross bedding. Some mud clasts.
3204.5-3216		Sandstone, fine to medium, mature sublitharenite. Patchy calcite cement. Good porosity. Tarry oil stain obscures bedding.
3216-3223		Sandstone, similar to above, no oil stain. Good planar low-angle cross bedding, variable set thickness. Some laminae with concentrations of mud clasts. Sharp basal contact.
3223-3224	Swift	Shale, medium - dark grey. Pyritic, non-calcareous.

Salmon #1 Conway
SENW 20 34N 11E
KB 2930, TD 7113
3316-3376 feet

FOOTAGE	FORMATION	DESCRIPTION
3316-3319	Gladstone	Shale, dark grey.
3319-3322.5		Shale, green-brown, silty. Less silt to base.
3322.5-3326		Shale, dark grey-green to black.
3326-3328		Mudstone, yellow-brown.
3328-3332		Shale, black. Lower Cretaceous flora recovered.
3332-3336		Siltstone, yellow-brown, with carbonaceous shale laminations. Thinly-bedded, with some low-angle planar cross bedding.
3336-3340		Mudstone, brown. Lower Cretaceous flora recovered.
3340-3343		Siltstone, dark grey, with carbonaceous shale laminations. Thinly-bedded, with minor trough cross bedding. Minor siderite.
3343-3346		Mudstone, green, grey and brown. Lower Cretaceous floras recovered.
3346-3355.5		Mudstone, yellow, massive. No flora recovered.
3355.5-3361	Swift	Ribbon sand, light colour. Silt fraction approx. 80%. Wavy-bedded, with some small-scale trough cross-bedding. Minor glauconite, pyrite. Slightly burrowed.
3361-3376		Sandstone, fine- to med.-grained, brown. Variable silt and clay content, wavy-bedded, with shale laminae. Some small lenses of hard coal at 3368. Variable glauconite, pyrite, carbonaceous material. Bioturbation moderate to abundant; less at base. DRS flora recovered.

Shell Blackfeet Tribal
SWSW 28 34N 8W
KB 3994, TD 5112
4532-4749 feet

FOOTAGE	FORMATION	DESCRIPTION
4532-4556	Gladstone (Calcareous)	Sandstone, poorly-sorted, submature feldspathic extralitharenite. Abundant plant debris. Large micritic nodules at 4549-4550
4556-4563.5		Sandstone, as above, with abundant thin coaly partings. Horizontally laminated.
4563.5-4596		Sandstone, as above. Well-developed low-angle planar cross-beds, with coaly partings. Micritic nodule zone, 4572-4574. Sharp basal contact
4596-4605		Mudstone, silty, maroon and green. Calcareous, with calcite-filled veins.
4605-4612	Gladstone	Siltstone, grey-green. Coarsens downwards. Contorted bedding.
4612-4616		Siltstone, grading down to v. fine sandstone. Small-scale cross bedding, soft sediment deformation structures.
4616-4662.5		Mudstone, silty, maroon and green.
4662.5-4670.5		Siltstone, shaly, green-grey. Some small-scale trough cross bedding, but dominated by soft sediment deformation structures.
4670.5-4671.5	Cut Bank	Sandstone, interbedded fine and medium grained.
4671.5-4680.5		Sandstone, fine to silty. Interbedded with dark carbonaceous shale, wavy-bedded. Good small-scale trough cross bedding in sandy beds.
4680.5-4698		Sandstone, interbedded v. fine- to med.-grained mature sublitharenite. Low-angle planar cross bedding in coarser beds, higher-angle small-scale cross bedding in finer beds. Shaly partings and small shale clasts, abund. carbonaceous material present. Black shale 4693-4695.5. Sharp basal contact.
4698-4718	Swift	Shale, dark grey, fissile. Some carbonaceous debris - some large fragments. V. glauconitic 4608-4618; some glauc. lenses above and below.
4718-4749	Rierdon	Shale, calcareous, interbedded with argillaceous limestone. Grey to green-grey.

Salmon #1 State A
SWSW 16 35N 11E
KB 2868; TD 3760
3178-3268 feet

FOOTAGE	FORMATION	DESCRIPTION
3178-3188	Beaver Mines	Mudstone, green-grey, silty. More silt, minor sand to base. Massive bedding.
3188-3190.5		Sandstone, poorly-sorted, silty, lithic. Fining upward. Somewhat bentonitic.Massive; flat-bedded near base. Sharp basal contact.
3190.5-3192		Siltstone, light brownish-grey. Massive.
3192-3197.5		Sandstone, poorly-sorted, lithic. Abundant clay matrix. Massive.
3197.5-3200		Mudstone, green-grey, arenaceous, grading down to purer brownish mudstone. Massive. Some brecciation near top.
3200-3203.5		Sandstone, med.-grained, extrafellitharenite. Abund. bentonitic clay matrix. Low-angle planar cross bedding. Minor siderite.
3203.5-3208		MISSING CORE
3208-3210		Sandstone, as above, calcareous.
3210-3218	Gladstone	Mudstone, green-grey to grey, variably silty, massive. Minor pyrite. Sharp basal contact.
3218-3220	Swift?	Siltstone, lt. grey, argillaceous. Wavy bedding, poss. light ribbon sand? Minor siderite and pyrite. Sharp basal contact.
3220-3223	Swift	Ribbon sand, dark colour. Minor calcite, coaly debris. No bioturbation.
3223-3240		Ribbon sand, dark colour. Wavy-bedded and thinly-laminated. Coaly debris present in upper half; minor siderite around 3230; glauconitic below 3231. Bioturbation moderate to rare in upper half, not noted below 3231. DRS flora recovered.
3240-3246		Siltstone, quartzose, argillaceous. Abund. dark shale laminae. Low-angle planar cross bedding. Load structures in upper 3 feet. Glauconitic, minor coaly debris.
3246-3259.5		Ribbon sand, dark. High silt content. Flat-bedded, some shale partings, poor development of lenticular beds. Variable but generally low glauconite content. Calcareous near base. No bioturbation noted. DRS flora recovered.
3259.5-3268		Ribbon sand, dark. Silt content not more than 30%. Minor pyrite. No bioturbation. DRS flora recovered.

Salmon #1 Schaller
20 37N 10E
KB 2808; TD 3800
3181-3321 feet

FOOTAGE	FORMATION	DESCRIPTION
3181-3213.5	Gladstone	Mudstone, dark green-grey, variably arenaceous and silty. Some thinly-bedded intervals. Minor pyrite, carbonaceous material. No flora recovered.
3213.5-3221		Sandstone, poorly-sorted, silty immature (sub)litharenite. Low-angle planar cross bedding.
3221-3224		Sandstone, med.-grained, extralitharenite. Low-angle planar cross bedding.
3224-3228		Mudstone, light green-brown, slightly silty. Minor pyrite.
3228-3242		Sandstone, v. fine to fine sideritic lithic quartzarenite. Fine lamination and wavy bedding. Sharp basal contact.
3242-3251	Swift	Ribbon sand, lt.-med. colour. Minor pyrite. Slightly bioturbated.
3251-3253		Shale, black, flat-bedded. Silty at base. Nondiagnostic flora recovered.
3253-3257.5		Sandstone, fine, submature sublitharenite. Some shaly laminae. Slightly bioturbated.
3257.5-3287		Ribbon sand, dark colour. Sand content decreases to base. Minor siderite, pyrite near base. Sand lenses with small-scale trough cross bedding. Little but variable bioturbation. DRS (nonmarine) flora recovered.
3287-3310		Siltstone, shaly. Some high-angle small-scale trough cross bedding. Minor pyrite. DRS (transitional to marine) flora recovered.
3310-3321		Shale, brownish-black. Upper Jurassic marine flora recovered.

Cardinal State-Darrow #8-8
SENE 8 37N 5E
KB 3724; TD 2997
2896-2926 feet

FOOTAGE	FORMATION	DESCRIPTION
2896-2897	Swift	Ribbon sand, dark colour. Silty to med.-grained sand, in lenses of variable thickness. Coal fragments present; non-glauconitic.
2897-2900		Sandstone, fine to med., submature litharenite. Abund. shaly clasts and partings, some large coal fragments. Cleaner to base. Minor oil stain.
2900-2905		Sandstone, as above, v. clean. Abund. shale partings. Minor glauconite, minor oil stain.
2905-2918		MISSING CORE
2918-2923		Sandstone, as above.
2923-2926		Ribbon sand, dark colour. Good lenticular bedding, quite variable development of sand lenses. Some small-scale trough cross bedding. No good glauconite or plant material. Bioturbation scarce to moderate.

Sumatra Fey-Apex 31-26
NWNE 26 37N 2E
KB 3740; TD 2720
2578-2810 feet (poor recovery)

FOOTAGE	FORMATION	DESCRIPTION
2578-2808	Gladstone	Sandstone, fine, quartzose. Fining upward slightly; less lithic to top. Excellent porosity, abund. oil staining.
2808-2810		Sandstone, fine, lithic. Abund. clay matrix, abund. shale clasts. Some carbonaceous debris and orange chert grains.

Albermont O'Hanlon et al Pugh #1
SENW 9 37N 4W
KB 3704; TD 2709
2520-2577; 2839-2889 feet

FOOTAGE	FORMATION	DESCRIPTION
2520-2531	Gladstone (Calcareous?)	Sandstone, poorly-sorted submature sublitharenite. Some mudstone interbeds.
2531-2533		Siltstone, sandy and shaly, grading down from above.
2533-2542		Shale, med. grey, slightly silty. Some floating sand grains. Abundant coaly material.
2542-2557		MISSING CORE
2557-2577		Numerous thin fining upward units, thickest about 20 cm. thick. Grades from sublithic sand to shale. Occasional thin pebbly beds, a few mudclasts. Possibly stacked crevasse splay deposits.
2577-2839		NO CORE
2839-2844	Cut Bank	Sandstone, med. to coarse extralitharenite. Massive, with some v. low-angle planar cross bedding. Mud clasts scattered in basal foot.
2844-2853		Sandstone, fine to v. fine, quartzose. Irreg. interbedded with silt, and more lithic coarser sand. Abund. pyrite.
2853-2889		Sandstone, med. to coarse, litharenite to extralitharenite. Overall fining upward. Well-developed pervasive low-angle planar cross bedding. Two thin coaly shale partings. Thin clean silica-cemented conglomerate near base.

CMG Black Butte 5-17
5-17-1-8W4
KB 3528; TD 3358
2866-2984 feet (wireline)

FOOTAGE	FORMATION	DESCRIPTION
2866-2871	Gladstone	Mudstone, lt. grey, silty, soft. No flora recovered.
2871-2872.5		Sandstone, v. fine-grained, somewhat lithic. Bentonitic clayey matrix, approx. 30%.
2872.5-2877		Mudstone, as above.
2877-2881		Sandstone, as above.
2881-2906		Mudstone, silty; maroon, green, and grey. Some thin interbedded fine-grained cross-bedded sands - poss. crevasse splays. Some plant debris; siderite in sands. No flora or fauna recovered.
2906-2913	Swift	Ribbon sand, light colour(?); sand 60%+. Some siderite. No gradation of colour downwards. Poss. not related to ribbon sand below.
2913-2920		Ribbon sand, dark colour; less than 30% sand. Thin flat sand lenses, minor bioturbation. Abund. siderite, no glauconite. DRS flora (nonmarine) recovered.
2920-2943		Dark ribbon sand; sand 60%+. Lenses thicker, bioturbation extensive, esp. in sandier intervals. Little siderite, no glauconite.
2943-2957		Sandstone, v. fine to fine sublitharenite. Fairly massive, w. abund. shale partings. Minor glauconite. (See Plate 4a)

2957-2970	Dark ribbon sand, sand content variable, up to 60%. Lenses gen. thin, bioturbation low. Some lenses definitely coarser - cherty litharenite to sublitharenite. Some siderite in sand lenses. DRS flora recovered. (See Plate 2a)
2970-2984	Shale, med. - dark grey. Upper contact unclear, not sharp. Shale similar to that in ribbon sand. Some v. thin silty intervals. Plant debris and pyrite present. Marine Upper Jurassic palynomorphs, nondiagnostic microfauna recovered.

CMG Stikr Black Butte 8-29
8-29-1-8W4
KB 3382; TD 3370
3060-3088 feet

FOOTAGE	FORMATION	DESCRIPTION
3060-3068	Gladstone	Sandstone, fine to med. litharenite. Massive, homogeneous. Lightly oil stained.
3068-3075		Sandstone, as above, but with intervals of flat bedding and cut-and-fill. Minor shale clasts.
3075-3079		Sandstone, fine - med. litharenite. Abund. light shaly-silty partings; good large-scale high-angle planar cross-beds. Some soft sediment faulting in basal foot. Sharp basal contact.
3079-3082	Swift	Shale, dark grey, silty, not micaceous. Abund. carbonaceous plant debris. No flora recovered (APA); indeterminate, prob. shallow marine flora recovered (SAJP).
3082-3088		Siltstone, shaly. Brecciated; no other bedding apparent - poss. reworked. Some plant debris. No flora recovered.

CMG Black Butte 7-29
7-29-1-8W4
KB 3404; TD 3270
3089-3114 feet

FOOTAGE	FORMATION	DESCRIPTION
3089-3096	Gladstone	Sandstone, mature(?) litharenite, (minor) variable clay matrix. Stacked sand units, numerous sharp contacts. Low-angle planar cross bedding. Lightly oil stained.
3096-3097		Mudstone, grey, with abund. sand and silt grains.
3097-3099		Sandstone, med. to fine, some clay matrix. A few pebbles.
3099-3101		Mudstone, grey-green, with floating sand grains. No flora recovered.
3101-3105		Sandstone, mature litharenite, med. to fine. Good planar cross bedding, some minor small-scale trough cross bedding. Erosional basal contact.
3105-3114	Swift	Ribbon sand, light colour. Very sandy at top, decreasing to 25-30% sand at base. Minor to moderate bioturbation. Darkens gradually downward over basal few feet. Siderite and plant debris very minor. No flora recovered.

McColl - Frontenac Union 16D-29
16-29-1-8W4
KB 3408; TD 3238
2910-3074 (wireline core)

FOOTAGE	FORMATION	DESCRIPTION
2910-2917	Gladstone	Mudstone, yellow, with silty brown zones.
2917-2943.5		Sandstone, v. fine to fine poorly-sorted lithic quartzarenite. V. immature, abund. clay matrix. Overall fining upward. Scattered siderite nodules, ~1-2 mm. diameter.
2943.5-2980		Sandstone, fairly mature fine- to med.-grained litharenite. Some finer, tight intervals. A few siderite nodules. Erosional basal contact.
2980-2985.5	Swift	Ribbon sand, light colour. Lenticular bedding not well-developed in upper three feet. No bioturbation. One sideritic zone at 2984. Fairly sharp colour change at base. No flora recovered.
2985.5-3063	"	Ribbon sand, dark colour. Sand content 20-30%, good cross bedding in sand lenses. Some sideritic zones, glauconite absent except near base. One 2-3 cm. layer of med. cherty sandstone at 3048. Bioturbation minor except in 3018 - 3025. DRS flora (nonmarine) recovered.
3063-3074	Rierdon	Shale, grey-green, calcareous, hard.

CMG Aden 6-36
6-36-1-10W4
KB 3260; TD 3004
2810-2832 feet

FOOTAGE	FORMATION	DESCRIPTION
2810-2832	Swift	Ribbon sand, light colour. Sand content approx. 40%. Slight darkening near base. Siderite conc. near top; minor pyrite, minor oil stain in larger sand lenses. Bioturbation minor throughout. (See Plate 1c)

Alcon Knappen
8-1-1-11W4
KB 3723; TD 3215
2856-2871 feet

FOOTAGE	FORMATION	DESCRIPTION
2856-2859	Gladstone	Sandstone, fine- to med.-grained mature lithic quartzarenite. A few pebbles near base.
2859-2864		Conglomerate; pebble-sized siltstone clasts, med.-grained sandstone matrix. Tightly cemented. Erosional basal contact.
2864-2867.5		Shale, dark grey-green. Minor pyrite, carbonaceous debris. Lower contact indistinct.
2867.5-2871		Shale, med. grey, silty, hard. No flora recovered.

Lloyd Black Coulee
7-30-1-11W4
KB 3215, TD 2835
2463-2503 feet (poor recovery)

FOOTAGE	FORMATION	DESCRIPTION
2463-2470	Beaver Mines	Sandstone, extralitharenite, poorly-sorted.
2470-2476		Shale, grey, soft, bentonitic. No flora recovered.
2476-2496		MISSING CORE
2496-2502.5	Gladstone (Calcareous)	Shale, med. grey, waxy, soft.
2502.5-2503		Limestone, tan, micritic. Slightly silty.

CMP Coutts 3-13
3-13-1-13W4
KB 3530; TD 2673
2590-2618 feet

FOOTAGE	FORMATION	DESCRIPTION
2590-2597	Swift	Sandstone, med. to coarse extralitharenite. Var. clay cement. Irregular porous oil staining zones.
2597-2601		Sandstone, fine - med. litharenite. More clay cement, some siderite. Mud flasers occur near base, grading down to lenticular ribbon sand.
2601-2618		Ribbon sand, light colour. Variable siderite concentration. Bioturbation v. minor.

Cabeen Exploration Coutts
11-23-1-15W4
KB 3418; TD 2575
2344-2374 feet

FOOTAGE	FORMATION	DESCRIPTION
2344-2349	Gladstone	Sandstone, poorly-sorted, dark shaly litharenite. Poss. fining upward (poor recovery). Abund. plant debris and coal fragments.
2349-2365		Sandstone and siltstone, irregularly interbedded. Sandstone v. fine to fine, mature litharenite.
2365-2374		Sandstone, med.-grained, extralitharenite. Var. clay cementation. Fairly massive.

Union - Buckley Nose
4-2-1-15W4
KB 3513; TD 2525
2405-2430 feet

FOOTAGE	FORMATION	DESCRIPTION
2405-2408	Cut Bank	Sandstone, fine - med. mature extralitharenite. Contains lenses of coarser sandstone. V. abund. pyrite, minor reworked(?) glauconite.
2408-2420	Swift	Shale, dark grey, somewhat silty, micaceous. Abund. silty lenses, abund. pyrite. Glauconite conc. in sharply-bounded lenses at 2412-2413, 2418-2420. Plant fragments fairly abundant. Marine Jurassic flora recovered.
2420-2430	Rierdon	Shale, dark grey-green, hard. Calcite-filled fractures at top.

Decalta Altair Milk River
2-4-1-17W4
KB 3808; TD 2815
2650-2811 feet

FOOTAGE	FORMATION	DESCRIPTION
2650-2660	Gladstone (Calcareous)	Mudstone, greenish, with minor interbedded silty mudstone and sandstone. No flora or fauna recovered.
2660-2675		Sandstone, v. fine to silty. Var. proportions of silica and calcite cement, var. clay content. Planar-bedded with some low-angle cross-beds, becoming convoluted near base. Thin shale laminae throughout.
2675-2678		Limestone, tan to greyish, argillaceous. Vuggy porosity near top. Abund. shell fragments.
2678-2685		Shale, calcareous, med. - dark grey. Sandy intervals near base. Abund. shell fragments. Brackish-water Aptian flora recovered.
2685-2736	Gladstone	Mudstone, mottled maroon and green. Some silt, minor organic and micaceous matter. No flora or fauna recovered.
2736-2748		Mudstone, silty, light green-grey. Some sandy intervals. Minor pyrite.
2748-2750.5		Shale, med. grey. No flora or fauna recovered.
2750.5-2753		Sandstone, v. fine to fine. Abund. clay matrix. Argillaceous in lower foot.
2753-2769	Cut Bank (Type)	Sandstone, v. fine to fine mature to submature sublitharenite. Mostly massive; a few intervals of moderate to high-angle cross bedding. Some shale laminae and mud clasts. Gen. fining upward. Some nodular siderite. (See Plate 3a)
2769-2780		Sandstone, fine to med. mature litharenite to extralitharenite. Numerous lag zones of mud clasts, coarser sand, and pebbles. Discontinuous zones of large- and small-scale cross bedding. Minor siderite, coaly debris, and calcite. (See Plate 2d)
2780-2788		Sandstone, as above. No pebble layers or mud clasts. Thin shale laminae.
2788-2789.5		Sandstone, v. fine to fine, interlaminated with grey mudstone. Small-scale cross bedding. No flora recovered.
2789.5-2797		Sandstone, med.-grained litharenite to extralitharenite. Homogeneous; a few mud clasts and shale laminae. (See Plate 3b)
2797-2800		Conglomerate, poorly-sorted extralitharenite matrix. Pebbles mostly chert. Some coaly material.
2800-2808		Sandstone, med. extralitharenite. Numerous pebbly lag zones. Some large-scale low-angle cross bedding. Sharp erosional basal contact.
2808-2811	Rierdon	Shale, calcareous, green-grey. Abund. pyrite.

Norex Twin River
11-5-1-18W4
KB 4113; TD 5112
3300-3329 feet

FOOTAGE	FORMATION	DESCRIPTION
3300-3303	Cut Bank	Sandstone, med.-grained mature litharenite, small-scale trough cross bedding. Oil staining, minor carbonaceous debris.
3303-3325		Sandstone, fine to med. mature litharenite. Fairly massive. A few pebbles and plant fragments, increasing to base. A few shaly intervals. Oil staining.
3325-3329	Swift	Ribbon sand, light colour. No glauconite, little siderite. Little bioturbation. Abund. plant debris and coal fragments. Poss. Upper Jurassic flora recovered (SAJP).

Westcoast Twin River
14-33-1-18W4
KB 3881; TD 3718
3440-3550 feet

FOOTAGE	FORMATION	DESCRIPTION
3440-3451	Gladstone (Calcareous)	Shale, calcareous, dark grey. Some shell fragments and coal.
3451-3457		Shale, grey-green. Minor floating sand grains. No flora recovered.
3457-3467	Gladstone	Sandstone, mature to submature sublitharenite, poorly-sorted. Gen. fining upward. Faint large-scale planar cross-beds.
3467-3472		Sandstone, v. fine. Fines up to siltstone and mudstone. No flora recovered.
3472-3485		Mudstone, mottled maroon and green. Minor plant debris.
3485-3503.5		Mudstone, greenish, with abund. silt and fine sandstone, irreg. interbedded.
3503.5-3506	Cut Bank	Sandstone, fine mature litharenite. Some low-angle planar cross bedding.
3506-3508		MISSING CORE
3508-3512		Sandstone, as above.
3512-3512.5		Mudstone, grey-green, hard. Some floating sand grains. No flora recovered.

3512.5-3526.5		Sandstone, mature to supermature fine - med. litharenite. Large-scale low-angle planar cross-beds. Minor pyrite.
3526.5-3534.5		Sandstone, as above, with thin beds of chert pebbles. Lag conglomerate at base with coaly debris. Minor siderite, pyrite.
3534.5-3541		Sandstone, as above, no pebbles.
3541-3550		Conglomerate, small chert pebbles in med.-grained lithic sand matrix. Some large-scale low-angle cross bedding. Minor coaly debris, pyrite. (See Plate 4b)

TNR Omega Comrey
10-27-2-5W4
KB 3060; TD 3522
3137-3197 feet

FOOTAGE	FORMATION	DESCRIPTION
3137-3158.5	Gladstone	Sandstone, v. fine to med., mature litharenite. Homogeneous; poss. some fining upward. A few mud clasts near base. Some low-angle planar cross bedding.
3158.5-3162		Sandstone, as above, with abundant mud clasts.
3162-3168.5		Sandstone, poorly-sorted immature sublitharenite. Numerous thin shale interbeds. Minor siderite. Lower Cretaceous nonmarine flora, no fauna recovered.
3168.5-3177		Shale, lt. grey, with abund. fine sand. Root tubes common; some plant debris. (See Plate 3d)
3177-3180		Shale, dark grey. Minor silt; abund. coaly material.
3180-3182		Siltstone and shale, lt. grey, finely laminated.
3182-3187		Sandstone, poorly-sorted immature extralitharenite. Abund. plant fragments, conc. in partings. Some low-angle planar crossbeds.
3187-3197		Sandstone, siltstone and shale, irregularly interbedded - appears disturbed (poss. soft sed. deformation). Minor plant debris. No flora recovered.

CMG Pender
10-34-2-7W4
KB 3080; TD 3340
3008-3028 feet

FOOTAGE	FORMATION	DESCRIPTION
3008-3010.5	Swift	Ribbon sand, light colour. Sand fine to v. fine lithic quartzarenite, in lenses a few cm. thick. V. sideritic in top foot. Minor burrowing. Lower contact fairly sharp.
3010.5-3021.5		Ribbon sand, dark colour. Well-devel. lenses; v. sandy 3013-3018. Moderate bioturbation - more in sandy zones. Abund. pyrite nodules, no glauconite. Sharp basal contact. DRS flora (nonmarine) recovered.
3021.5-3024		Mudstone, silty and sandy. Appears to be similar to ribbon sand, but reworked so that bedding destroyed. Poss. some low-angle large-scale planar crossbeds. DRS flora recovered.
3024-3028		Ribbon sand, dark colour. Sand less than 10%, lenses v. thin and flat. Pyritic, less silt, mica and plant debris. No glauconite. DRS flora recovered.

CMG Pan Am Pendor
7-29-2-8W4
KB 3002; TD 3104
2780-2819 feet

FOOTAGE	FORMATION	DESCRIPTION
2780-2774	Gladstone	Siltstone, lt. grey, w. abund. med. to coarse chert grains. Bedded chert and chert conglomerate in top two feet; chert-filled fractures throughout.
2774-2788.5		Sandstone, med.-grained mature extralitharenite. Some large-scale planar cross bedding, a few mud clasts. Oil staining. Erosional basal contact.
2788.5-2798	Swift	Ribbon sand, light colour. Sand greater than 70%, coarsening up. Flaser and wavy-bedded near top. Abund. siderite in irregular zones, slight bioturbation. Gradational lower contact.
2798-2819		Ribbon sand, dark colour. Sand approx. 40%; general coarsening-up trend. Lenses have excellent small-scale trough cross bedding; some contain light oil stain. Some pyrite nodules, minor siderite, no glauconite. Bioturbation slight, moderate in a few zones. A few zones, up to 4 cm thick, of v. thinly laminated shale and siltstone. DRS flora recovered. (See Plate 2b)

CMG Pan Am Pender
8-31-2-8W4
KB 2850; TD 2888
2565-2630 feet

FOOTAGE	FORMATION	DESCRIPTION
2565-2574	Beaver Mines	Conglomerate, lithic pebble-sized clasts, grey shale and silt matrix. Poor recovery.
2574-2576	Gladstone	Mudstone, yellow, soft. No flora recovered.
2576-2582		Sandstone, fine litharenite, with a few chert pebbles. Very tightly cemented by clays.
2582-2612		Sandstone, fine to med. mature litharenite. Massive; some large-scale low-angle planar crossbeds near base. Some intervals of siltstone pebbles and mud clasts near base. Oil staining in basal four feet. Basal contact unclear (sharp?).
2612-2613.5	Swift	Shale, v. silty and sandy, lt. grey. Poss. same as underlying unit, but bedding is destroyed.
2613.5-2618		Ribbon sand, light colour. Sandier at base. One pyrite nodule noted. Scattered siderite nodules, some conc. in detrital(?) lenses. Minor bioturbation. Slightly darker to base.
2618-2626		Sandstone, fine to v. fine sublitharenite. Scattered flasers and silty shale partings. Upper contact and bedding indistinct - poss. some low-angle crossbeds. Minor siderite.
2626-2630		Ribbon sand, as above. Moderate burrowing, a few pyrite nodules, sl. darker.

Gas Exploration Pinhorn #2
14-25-2-10W4
KB 2891; TD 2805
2565-2645 feet (wireline core)

FOOTAGE	FORMATION	DESCRIPTION
2565-2582.5	Swift	Sandstone, fine - med., sublithic. Bedding not apparent. Minor siderite.
2582.5-2614		Ribbon sand, light colour. High sand content, wavy bedding. Some sand lightly oil stained. Glauconitic(?) near base. Grades down to darker ribbon sand.
2614-2616		Ribbon sand, dark colour. Sand content decreases down; may grade into shale below. Siderite and glauconite present.
2616-2630		Shale, sl. silty, med. grey. Abund. plant material.
2630-2635		MISSING CORE
2635-2645	Rierdon	Shale, grey-green, calcareous, hard.

New British Comrey #1
6-15-3-8W4
KB 2994; TD 3480
3054-3113 feet (wireline core, poor recovery)

FOOTAGE	FORMATION	DESCRIPTION
3054-3061	Gladstone	Mudstone, med. - dark grey, soft. No flora recovered.
3061-3078		MISSING CORE
3078-3088		Mudstone, grey, soft.
3088-3093		Siltstone, with abund. shale and fine sand. No distinct bedding, poss. root traces.
3093-3097	Swift	Ribbon sand, dark colour. Wavy to sl. lenticular bedding. No glauconite. DRS flora recovered.
3097-3113		Siltstone, quartzose. Indistinctly interbedded with fine sandstone and shale. Minor glauconite.

CMG Pender
10-20-3-7W4
KB 2930; TD 3180
2875-2897 feet

FOOTAGE	FORMATION	DESCRIPTION
2875-2888	Gladstone	Sandstone, fine - med. sublitharenite. Thin stacked fining upward sequences with little internal bedding. Some short intervals of mud clasts. Chert pebble conglomerate in basal half foot. Erosional basal contact. (See Plate 3c)
2888-2897	Swift	Ribbon sand, dark colour. Sand 40-50%. Minor siderite. Moderate bioturbation. DRS flora (nonmarine) recovered.

Murphy et al Pakowki
10-28-3-7W4
KB 2924; TD 3220
2870-2930 feet

FOOTAGE	FORMATION	DESCRIPTION
2870-2872	Beaver Mines	Mudstone, grey-green, hard. Somewhat bentonitic. Minor plant material.
2872-2875		Mudstone, grey, with abund. coal. No flora recovered.
2875-2878		Mudstone, w. abund. silt and sand. Micaceous, some plant debris. Poss. root traces.
2878-2880.5		Mudstone, dark grey, silty. Some plant material.
2880.5-2888.5	Gladstone	Mudstone, grey and green, slightly calcareous. Minor bentonite. No flora recovered.
2888.5-2890		Mudstone, yellow, slightly calcareous. Some plant remains.
2890-2893.5		Shale, med. grey, sl. calcareous. Minor fossil fragments and plant debris. No flora recovered.
2893.5-2900.5		Mudstone, med. grey, w. abund. sand. Fining upward from unit below. Scattered shale pebbles; sl. calcareous, with a few fossil fragments. Poss. plant roots.
2900.5-2913		Sandstone, poorly-sorted, v. fine to coarse extralitharenite. Planar-bedded. Some intervals of interbedded shale and mud clasts. Erosional basal contact.
2913-2914.5		Mudstone, lt. green. Some floating sand grains; minor siderite.
2914.5-2916.5		Mudstone, brown-yellow, silty, micaceous. No flora recovered.
2916.5-2917		Shale, lt. grey. Grades into mudstone above.
2917-2917.5		Shale, dark grey, v. coaly. Grades into shale above.
2917.5-2918.5	Swift	Shale, dark grey. Silty lenses present, more common to base. Small-scale soft sed. faulting evident. Appears to grade up from ribbon sand below. DRS flora (nonmarine) recovered.
2918.5-2924		Ribbon sand, dark colour. Sand 50%+; in well-devel. lenses, w. some intervals of flaser bedding. Abund. pyrite, some in large nodules; no glauconite. Little or no bioturbation.
2924-2930		Ribbon sand, much less sandy. Only minor bioturbation - mostly sand-filled burrows. No glauconite.

Home CMG Pender
11-4-3-8W4
KB 2988; TD 3060
2775-2825 feet

FOOTAGE	FORMATION	DESCRIPTION
2775-2778	Gladstone	Mudstone, lt. grey, bentonitic. Some floating sand grains.
2778-2778.5		Sandstone, poorly-sorted, v. immature sublitharenite. Bentonitic clay matrix. Minor pyrite.
2778.5-2794		Sandstone, sorting fair to poor, (sub)litharenite. Some fining up; more lithic to base. Fairly mature and cleaner, with some oil staining near base. Massive, with some low-angle cross bedding. Erosional basal contact.
2794-2799		Shale, silty, dark grey-green, waxy. Some floating sand grains and minor plant debris. No flora recovered (APA and SAJP).
2799-2805	Swift	Ribbon sand, dark colour; sl. lighter at top. Sand 40-50%. Minor burrowing. No glauconite.
2805-2825		Ribbon sand, dark colour. Sand coarser; becomes fine- to med.-grained near base. Bioturbation moderate. Minor glauconite.

McColl - Frontenac Union 9A-22
9-22-3-8W4
KB 2957; TD 3183
2815-2925 feet (wireline core)

FOOTAGE	FORMATION	DESCRIPTION
2815-2825	Gladstone	Sandstone, poorly-sorted, immature litharenite. Massive.
2825-2835		MISSING CORE
2835-2855		Sandstone, as above. Fairly massive; some interbedding of coarser and finer sand. Poor recovery; basal contact not present.
2855-2865	Swift	Ribbon sand, intermediate colour. Sand 85-90%, well-sorted v. fine quartzarenite. Flaser-bedded; good small-scale trough cross bedding in sand. Minor siderite, poss. minor glauconite.
2865-2875		MISSING CORE
2875-2900		Ribbon sand, dark colour. Sand content decreases downward to approx. 20%; occurs in thin lenses. Minor siderite and glauconite. Bioturbation variable. No flora or fauna recovered.
2900-2920		Siltstone, argillaceous. Some finely laminated intervals. V. glauconitic near base; somewhat calcareous. Poss. highly-disturbed ribbon sand.
2920-2920.5		Conglomerate; clasts of chert pebbles and belemnites, dark shale matrix. (See Plate 1a)
2920.5-2925	Rierdon	Shale, grey-green, calcareous, soft.

CMG Pan Am Pendor
6-19-3-9W4
KB 3013; TD 3035
2772-2783 feet

FOOTAGE	FORMATION	DESCRIPTION
2772-2774	Swift	Sandstone, med.-grained extralitharenite. Some low-angle crossbeds. V. sideritic, oil staining. Sharp basal contact.
2774-2775		Sandstone, much as above, but finer. Some layers of silty shale material - mud clasts or flasers?
2775-2783		Ribbon sand, light colour. Sand 70%+, wavy- and flaser-bedded. V. sideritic at top, less so to base. Darkens slightly to base. No bioturbation. Indeterminate flora recovered (SAJP).

Mesa Target Milk River
11-12-3-17W4
KB 3496; TD 3170
2985-3025 feet

FOOTAGE	FORMATION	DESCRIPTION
2985-2987.5	Gladstone	Mudstone, silty, mottled maroon and green.
2987.5-2993		Mudstone and siltstone, arenaceous, green. Fining upward, w. some low-angle cross bedding. Minor plant debris.
2993-3025	Cut Bank	Sandstone, fine to med. mature litharenite. Low-angle cross bedding, esp. near base. Some mud clasts at 3010. Substantial oil staining in upper part. Minor siderite.

Barnwell Milk River
1-13-3-17W4
KB 3456; TD 3130
2959-2980 feet

FOOTAGE	FORMATION	DESCRIPTION
2959-2960	Cut Bank	Sandstone, v. fine to fine, mature(?) litharenite. Abund. siderite. Oil staining.
2960-2980		Sandstone, med. to coarse supermature litharenite. Consistent large-scale low-angle planar cross bedding. Oil saturated.

WRS Sage Creek
7-8-6-4W4
KB 3390; TD 4220
3620-3739 feet

FOOTAGE	FORMATION	DESCRIPTION
3620-3648	Beaver Mines	Sandstone, poorly-sorted immature extrafellitharenite. Var. calcite and clay cement. Mud clasts 3624-3631. Minor plant debris.
3648-3653		Mudstone, arenaceous and silty, green to yellow. Root zone - poss. soil. No flora recovered.
3653-3659.5		Sandstone, med. to fine, lithic. Minor shale partings, some plant debris. Grades into shale below.
3659.5-3664		Mudstone, silty, lt. to med. grey. Some plant debris; root traces evident. Aptian-Albian nonmarine flora recovered. Grades into coaly zone below.
3664-3665.5		Coal and coaly shale.
3665.5-3667.5		Siltstone, shaly, with med. to coarse sandstone at base. Abund. plant debris. Erosional basal contact.
3667.5-3677.5	Swift	Ribbon sand, light colour. Sand 40-50%, in thin lenses. Bedding indistinct at top, becomes more clear downward. Some small-scale soft sediment faulting. Siderite abundant; heavy conc. at 3671.5-3672.5.
3677.5-3686.5		Ribbon sand, light colour. Much sandier; wavy- and flaser-bedded. Minor bioturbation. Indistinct lower contact - gradation to dark colour over 15 cm.

3686.5-3714		Ribbon sand, dark colour. Quite uniform - sand 30-40%, in thin lenses. Some pyrite nodules, minor siderite, no glauconite. Mod. bioturbation; a few churned zones. DRS flora (nonmarine) recovered.
3714-3738		Shale, silty, med. to dark grey. Scattered polished chert granules. Minor glauconite, pyrite and plant debris. Upper part could be churned ribbon sand. Upper Jurassic marine palynomorphs recovered.

CMG Home Manyberries
6-22-4-4W4
KB 3184; TD 3878
3465-3488 feet

FOOTAGE	FORMATION	DESCRIPTION
3465-3488	Swift	Ribbon sand, light at top, darkening gradually downward to dark colour by 3482. Sand 70%+; some lenses quite thick. Abund. siderite in top 5-6 feet. Abund. large pyrite nodules in dark section; no glauconite. Bioturbation variable, but not present near top. DRS flora recovered near base.

CMG Pakowki
8-2-4-7W4
KB 2828; TD 3243
2870-2900 feet

FOOTAGE	FORMATION	DESCRIPTION
2870-2880.5	Gladstone	Sandstone, fine mature sublitharenite. Fairly massive; some indistinct planar low-angle crossbeds. Erosional basal contact.
2880.5-2881	Swift	Shale, dark grey, sl. silty. Abund. plant debris, micaceous. DRS flora recovered.
2881-2882.5		Sandstone, fine well-sorted sublitharenite. Some shale partings; flaser- and wavy-bedded. A few pyrite nodules.
2882.5-2885		Ribbon sand, dark colour. Sand content variable, averaging 50%; sublitharenite, fine, well-sorted. Bioturbation moderate to intense. Glauconitic (poss. reworked). DRS (nonmarine) flora recovered.
2885-2885.5		Sandstone, fine - med. sublitharenite. Abund. mud clasts; some form partings. Abund. glauconite.
2885.5-2900		Sandstone, v. fine to fine sublitharenite. Completely composed of small-scale trough cross beds. A few shale partings. Patchy conc. glauconite. (See Plate 2c)

CMG Pender
7-8-4-7W4
KB 2819; TD 3115
2750-2808 feet

FOOTAGE	FORMATION	DESCRIPTION
2750-2755	Gladstone	Siltstone, arenaceous and argillaceous, lt. grey to white. Minor pyrite.
2755-2769		Sandstone, med.-grained mature to supermature litharenite, becoming more lithic to base. Planar-bedded with some planar low-angle cross bedding. A few scattered shale clasts. Basal contact unclear.
2769-2791	Swift	Ribbon sand, light colour. Sand content low; in v. thin flat lenses. Grades down to dark colour. V. minor siderite. Indeterminate flora recovered (SAJP).
2791-2808		Ribbon sand, dark colour. Sand 20%, in thin flat lenses; a few lenses sl. coarser, sideritic. Abund. coaly fragments and pyrite (dissem. and nodular). DRS flora (APA). Upper Jurassic flora (SAJP), no fauna recovered.

CMG Pendor
10-7-4-7W4
KB 2851; TD 3000
2804-2853 feet

FOOTAGE	FORMATION	DESCRIPTION
2804-2808	Gladstone	Mudstone, grey. Poor recovery.
2809-2816		Sandstone, poorly-sorted immature litharenite. Bentonitic clay matrix. Some plant debris; root traces.
2816-2822		Mudstone, lt. to med. grey. Sl. calcareous, minor plant debris. No flora recovered.
2822-2832	Gladstone?	Mudstone, yellow, sl. calcareous. No flora (APA), possible Upper Kimmeridgian flora (SAJP) recovered.
2832-2837		Mudstone, brown-yellow. Sl. calcareous, somewhat bentonitic. No flora (APA), indeterminate flora (SAJP) recovered.
2837-2844		Mudstone, lt. grey, silty. Minor bentonite. Poss. root traces, some plant debris. Basal contact not present; resembles ribbon sand below. Indeterminate flora recovered (SAJP).
2844-2847	Swift	Ribbon sand, light colour. Sand 20-30%, v.-fine to fine, coarser to base.
2847-2853		Ribbon sand, dark colour. Lithic quartzarenite more abund., coarser, and in thicker lenses to top. Minor bioturbation - some trails on parting surfaces near top. DRS flora recovered.

CMG et al Pendor
8-1-4-9W4
KB 2879; TD 3119
2853-2883 feet

FOOTAGE	FORMATION	DESCRIPTION
2853-2856	Gladstone	Sandstone, med.-grained submature litharenite. Massive except for v. low-angle planar crossbeds in basal foot. Erosional basal contact. (See Plate 5b)
2856-2877	Swift	Ribbon sand, light colour. Sand approx. 20%, mostly in thin flat lenses. Graded bedding in sand layers in top two feet. Abund. siderite, esp. near top; some in detrital concentrations. Scattered pyrite nodules. Minor bioturbation. Gradual darkening below 2863.
2877-2883		Ribbon sand, intermediate to dark colour. Sandier than above, esp. in 2879-2881; coarser immature lithic quartzarenite. More heavily burrowed; churned in sandy interval. Minor glauconite and pyrite.

Empire State Smice
11-6-4-10W4
KB 3130; TD 3081
2845-2889 feet

FOOTAGE	FORMATION	DESCRIPTION
2845-2858	Gladstone	Sandstone, fine to med. mature extralitharenite. Faint planar bedding. Fining upwards. Minor plant debris.
2858-2876		Sandstone, med. to coarse extralitharenite. Calcite and clay cement. Abund. siderite, conc. in bands; abund. coaly material, esp. at base.
2876-2889		Sandstone, med. to fine mature extralitharenite. Very massive, homogeneous. Minor plant debris.

California Standard Birdsholm Province #1
14-33-4-11W4
RT 3048; TD 3131
2930-2971 (wireline)

FOOTAGE	FORMATION	DESCRIPTION
2930-2935.5	Gladstone	Mudstone, lt. grey, somewhat bentonitic. Scattered floating sand grains.
2935.5-2939		Sandstone, med.-grained mature extralitharenite. Clay and calcite cement.
2939-2940		Mudstone, lt. grey, a few floating sand grains. No flora recovered.
2940-2959		Sandstone, fine to med. mature sublitharenite. Massive. Minor dissem. pyrite, plant debris, siderite. Minor calcite and clay cement.
2959-2960		Sandstone, med.-grained litharenite. Abund. plant debris; some calcite cement. Erosional basal contact.
2960-2971	Rierdon	Shale, green-grey, hard, calcareous.

Shell Crow
14-21-4-13W4
KB 3056; TD 3081
838-871.76 metres (2749-2860 feet)

FOOTAGE	FORMATION	DESCRIPTION
2749-2749.5	Beaver Mines	Sandstone, poorly-sorted extralitharenite. Tightly cemented. Minor carbonaceous debris.
2749.5-2775	Gladstone	Mudstone, mottled maroon and green. Minor silt.
2775-2777		Siltstone, laminated. Fractured; some disturbed laminae. Erosional basal contact.
2777-2781		Mudstone, lt. grey, silty. Minor carbonaceous debris. Probable root zone.
2781-2800.5		Mudstone, grey to grey-green. Irregular silty zones.
2800.5-2805.5		Mudstone, mottled maroon and green. Limonitic bands and nodules.
2805.5-2860	Rierdon	Shale, dark grey-green, calcareous. Numerous limestone beds up to 30 cm. thick.

Westcoast Crow Lake
1-10-4-14W4
KB 3088; TD 2873
2720-2740 feet

FOOTAGE	FORMATION	DESCRIPTION
2720-2721	Swift	Shale, silty, green-grey. Contains one 5-cm. rounded body of glauconite with chert granules. Dissem. pyrite. Nondiagnostic microfauna recovered.
2721-2740		Shale, as above, no glauconite. V. minor calcite. Oxfordian microfauna recovered.

Trans-Canada WCC #1
15-15-4-16W4
KB 3161; TD 3091
2840-2884 feet

FOOTAGE	FORMATION	DESCRIPTION
2840-2842.5	Swift?	Sandstone, v. fine to fine. More poorly-sorted to base. Abund. plant material.
2842.5-2844		Siltstone, laminated w. shaly siltstone; poss. ribbon sand. Calcareous, sideritic; some plant debris.
2844-2850	Swift	Shale, med. to dark grey, soft. Some bentonitic zones. Increasingly glauconitic to base. Upper Jurassic (marine) flora recovered.
2850-2852.5		Shale, as above, containing 40% glauconite pellets.
2852.5-2864		Siderite, in silt- to v. fine sand-sized pellets.
2864-2870	Rierdon	Shale, grey-green, hard.
2870-2884		Shale, as above. Calcareous, with very calc. zones.

Conrad Province 75-35-C
12-35-4-16W4
KB 3101; TD 3060
2830-2878 (wireline)

FOOTAGE	FORMATION	DESCRIPTION
2830-2837.5	Gladstone	Mudstone, dark grey, soft. Dissem. pyrite. Aptian-Albian (nonmarine) flora, Lower Cretaceous fauna recovered.
2837.5-2838		Sandstone, fine, lithic, fairly mature.
2838-2838.5		Shale, med. to dark grey, soft. No flora or fauna recovered.
2838.5-2848	Swift	Ribbon sand(?), light colour. Poorly-developed wavy bedding. Abund. soft sediment deformation. Some massive v. fine to fine bodies of immature sublitharenite. Siderite conc. in thin zones. Unclear basal contact.
2848-2852		Ribbon sand, dark colour. Sand 50-80%; flaser and lenticular bedding. Sand fine to med.-grained, sublithic. Minor soft sed. faulting. Moderate bioturbation. Glauconitic, w. minor siderite. Lower contact not distinct.
2852-2866.5		Shale, dark to med. grey. Some v. fine silty horizons. Upper Jurassic (marine) flora, non-diagnostic fauna recovered.
2866.5-2868		Shale, as above, with 30% glauconite pellets.
2868-2869		Siderite, in silt-sized pellets.
2869-2872	Rierdon	Shale, green-grey, firmly consolidated.
2872-2878		Shale, as above. Calcareous, with limestone bands.

Amisk Del Norte Warner
16-13-4-17W4
KB 3325; TD 3230
2978-3120 feet

FOOTAGE	FORMATION	DESCRIPTION
2978-2998.5	Beaver Mines	Mudstone, silty, mottled maroon and green. Silty zones in upper half; slightly calcareous in middle.
2998.5-3004		Shale, dark grey, hard. Grades into siltstone below. Aptian-Albian (nonmarine) flora, non-diagnostic fauna recovered.
3004-3018		Siltstone, med. grey, argillaceous. Some planar bedding and low-angle planar cross bedding. Abund. plant debris.
3018-3060		MISSING CORE
3060-3078	Gladstone	Siltstone, med. grey. Thin shale breaks. No flora or fauna recovered.
3078-3088.5		Sandstone, v. fine to fine, lithic. Fining up; poss. root zone at top.
3088.5-3091		Siltstone, lt. grey. Some mud clasts. Minor carbonaceous material.
3091-3099		Sandstone, fine litharenite. Low-angle large-scale cross bedding. Oil saturated, esp. in less-cemented zones.
3099-3101		Siltstone, lt. grey.
3101-3104		Sandstone, poorly-sorted conglomeratic immature litharenite. Shale pebbles approx. 20%. No bedding visible. Pyrite nodules conc. at erosional basal contact. Some oil staining.
3104-3107.5	Swift	Shale, grey, firmly consolidated. No flora, poss. Upper Jurassic microfauna recovered.
3107.5-3120	Rierdon	Shale, grey-green, v. calcareous. Upper Jurassic (marine) flora, Oxfordian-Callovian fauna recovered.

Home CMG Craigower
10-3-5-4W4
KB 3483; TD 4205
3822-3912 feet

FOOTAGE	FORMATION	DESCRIPTION
3822-3829	Swift	Ribbon sand, light colour. Darkens gradually downward, sharply at base. Abund. siderite at top, decreases to none at base. Bioturbation v. slight.
3829-3840		Ribbon sand, dark colour. Thin sand lenses, w. some fine cross bedding. V. little bioturbation. DRS flora recovered.
3840-3852		Ribbon sand, dark, sandier. Sand fraction quartzose siltstone to v. fine lithic quartzarenite. Some lenses up to 2 cm. thick. Variable burrowing, but generally more than above interval.
3852-3870		Ribbon sand, w. abund. irregular beds of fine - med. sublithic sandstone up to 10-15 cm. thick. Some glauconite; some large pyrite nodules. Basal boundary rather arbitrary.
3870-3885		Ribbon sand; less sandy, more lenticularly-bedded. Sand silt-sized to med.-grained. Less pyrite, some heavy glauconite concentrations.
3885-3906		Ribbon sand; more sandy, like 3852-3870 interval. Mature litharenite. Some glauconitic horizons.
3906-3906.5		Shale, calcareous. Abund. siderite and pyrite. Contacts not present. DRS flora recovered.
3906.5-3912	Rierdon	Shale, grey-green, v. calcareous. Some fossil fragments.

Home Craigower
10-4-5-4W4
KB 3365; TD 4189
3656-3718 feet

FOOTAGE	FORMATION	DESCRIPTION
3656-3664	Beaver Mines	Sandstone, silty to fine immature feldspathic extralitharenite. Low-angle planar cross bedding, more regularly laminated to base. Some coaly shale partings.
3664-3678		Siltstone, argillaceous, w. irreg. sandy lenses and layers. Some low-angle cross bedding; cut-and-fill structures. Some iron oxide bands. Lower Cretaceous flora recovered.
3678-3684.5		Conglomerate, mud matrix. Shale, chert and coal clasts, v. coarse sand to pebble size. Some intervals with sand matrix. No bedding observed. Gradational basal contact.
3684.5-3694		Sandstone, poorly-sorted mature feldspathic extralitharenite. V. abund. coaly lenses and dissem. debris. Some coarser sand lenses near base.
3694-3697		Quartzarenite, gen. fine, supermature. Massive. Oil staining.
3697-3704		Sandstone, lithic, v. shaly. Root traces, some plant material.
3704-3718	Swift	Ribbon sand, light colour. Sand 50-80%. Bedding unclear at top; grades down to good lenticular bedding. Minor bioturbation.

Pacific Manyberries
14-32-5-4W4
KB 3759; TD 4405
4119-4164 feet

FOOTAGE	FORMATION	DESCRIPTION
4119-4125.5	Gladstone	Sandstone, poorly-sorted immature litharenite. Scattered shale pebbles. Cleaner, lightly oil stained in basal feet.
4125.5-4128		Sandstone, med. - coarse mature litharenite. Fining upward. Some shale partings; minor coal fragments and siderite.
4128-4131		Conglomerate. Sandstone matrix as above, w. abund. mud clasts.
4131-4142.5	Swift	Shale, grey-green. Iron oxide staining at top. Upper Jurassic (prob. marine) flora (APA), indeterminate flora (SAJP), non-diagnostic fauna recovered.
4142.5-4143		Siderite, silt-sized pellets, w. minor quartzose silt.
4143-4147		Shale, as above. V. slightly calcareous. Minor pyrite and fossil fragments. Upper Jurassic (marine) flora, Oxfordian fauna recovered.
4147-4148		Siderite, as above.
4148-4164	Rierdon	Shale, grey-green, calcareous, hard. Scattered megafossil fragments. Fossil ages as in shale above.

CMG 11-23
11-23-5-14W4
KB 2877; TD 3180
2805-2836 feet

FOOTAGE	FORMATION	DESCRIPTION
2805-2807	Beaver Mines	Mudstone, grey-green, soft.
2807-2808.5		Siltstone, argillaceous, lt. grey. Well consolidated, slightly bentonitic.
2808.5-2810.5		Mudstone, dark grey-green. No flora or fauna recovered.
2810.5-2813		Sandstone, fine, lithic; fines upward. Minor plant debris and pyrite.
2813-2815		Siltstone, grey, hard. Some disturbed bedding. Minor coal fragments.
2815-2818.5		Sandstone, silty to fine fellitharenite. Planar bedding and low-angle planar cross bedding; shale partings. Abund. siderite, some plant debris and pyrite.
2818.5-2822		Shale, dark grey. Fairly abund. coaly debris. Lower Cretaceous, prob. Aptian-Albian (nonmarine) flora, Lower Cretaceous fauna recovered.
2822-2828		Sandstone, v. fine to fine, lithic. No bedding at top; some laminations and shale partings near base; Plant debris, pyrite present.
2828-2831		Siltstone, v. shaly, grey, hard. Minor plant debris.
2831-2836.5		Sandstone, as above. Massive, except for some shale partings.

2835.5-2838	Gladstone	Mudstone, silty, med. grey. No flora, Lower Cretaceous fauna recovered.

Conrad Province
11-21-5-15W4
KB 3102; TD 3168
2810-2890 feet .

FOOTAGE	FORMATION	DESCRIPTION
2810-2818	Gladstone	Mudstone, maroon and green, silty. No flora or fauna recovered.
2818-2821.5		Sandstone, v. silty. Very tightly consolidated.
2821.5-2832		MISSING CORE
2832-2838		Sandstone, v. fine to fine, with interbedded siltstone. Some shale partings, soft sediment deformation. Minor siderite, plant debris.
2838-2843.5		Shale, med. to dark grey, fissile. Lighter, more silty to top. Lower Cretaceous (nonmarine) flora, no fauna recovered.
2843.5-2851		Sandstone, med. to coarse mature litharenite. Fairly massive.
2851-2852		Mudstone, dark grey, soft.
2852-2870.5		Sandstone, fine to v. fine litharenite. Bedding indistinct - massive near top, planar laminae to base. Siderite throughout, but conc. in zones. Some plant material.
2870.5-2888	Swift	Shale, med. - dark grey, silty, micaceous. Iron-rich concretions. Some plant debris, scattered glauconite. Lower bound not distinct. Upper Jurassic (marine)flora, nondiagnostic fauna recovered.
2888-2890	Rierdon	Shale, green-grey, hard, calcareous. Minor pyrite.

Pamoil Liberty Tyrell
15-30-5-16W4
KB 3123; TD 3250
3077-3100 feet

FOOTAGE	FORMATION	DESCRIPTION
3077-3081	Gladstone	Sandstone, fine-grained (sub)litharenite. Massive. Scattered shale pebbles. Variable oil stain. Sharp basal contact.
3081-3100		Mudstone, sl. silty, mottled maroon and green, hard. Minor plant debris. No flora recovered.

Pamoil Liberty Tyrell
2-36-5-17W4
KB 3134; TD 3205
3111-3156 feet

FOOTAGE	FORMATION	DESCRIPTION
3111-3115.5	Gladstone	Siltstone, green, hard.
3115.5-3118.5		Siltstone, quartzose. Hard, tightly consolidated.
3118.5-3131.5	Cut Bank	Sandstone, med.-grained mature litharenite. Planar-bedded. Oil saturated, except for irreg. finer tight zones.
3131.5-3132.5		Conglomerate. Mud clasts in sandstone matrix, as above. No oil stain.
3132.5-3146		Sandstone, as above. Becomes dirtier, less mature, and contains less oil near base.
3146-3148		Conglomerate. Mud clasts in matrix of poorly-sorted extralitharenite. V. well cemented; no oil stain.
3148-3151		Sandstone, med.-grained litharenite. Scattered mud clasts. Some oil staining. Sharp basal contact.
3151-3152.5	Cut Bank?	Shale, green, hard. Minor pyrite. No flora or fauna recovered.
3152.5-3156		Shale, med. to dark grey, hard. No flora or fauna recovered.

CMG Etzikom
6-31-6-8W4
KB 2846; TD 3233
3067-3090 feet

FOOTAGE	FORMATION	DESCRIPTION
3067-3079	Gladstone	Sandstone, med. to coarse mature (sub)litharenite. Fining up; massively-bedded. Oil staining. Sharp basal contact.
3079-3079.5	Rierdon?	Shale, green-grey, calcareous, soft. No flora, nondiagnostic fauna recovered.
3079.5-3080		Bentonite, pure, massive, steel blue colour.
3080-3090	Rierdon	Shale, green-grey, calcareous. Marine macrofossils.

Calstan Legend Province
7-31-5-12W4
KB 2884; TD 2912
2835-2913 feet

FOOTAGE	FORMATION	DESCRIPTION
2835-2843.5	Gladstone	Sandstone, fine to v. fine submature litharenite. Large-scale low-angle cross bedding. V. homogeneous.
2843.5-2852.5		Sandstone, med.-grained calcareous sublitharenite. Fines upward.
2852.5-2893.5		Sandstone, med.-grained, v. well-sorted mature to supermature extralitharenite. Poor recovery in some intervals. Fairly massive. Variable siderite; more siderite and pyrite, coarser to base. Sharp basal contact, although some chert grains appear to have penetrated into sediment below(?)
2893.5-2897	Swift	Sandstone, v. fine to silty mature quartzarenite. Sideritic, somewhat micaceous. Grades down to ribbon sand; flaser bedding in lower part.
2897-2907	"	Ribbon sand, light colour. Sandiest at top, sand decreasing downward. Abund. siderite at top; glauconitic(?) below 2902. Bioturbation slight to moderate. Fairly sharp lower contact.
2907-2913	Swift	Ribbon sand, dark colour. Lenticular bedding at top; becomes a shale w. silty intervals at base. No flora (APA), Bajocian-Bathonian(?) flora (SAJP) recovered.

Amoco A-1 Legend
10-5-6-13W4
KB 3055; TD 5625
2831-2891 feet

FOOTAGE	FORMATION	DESCRIPTION
2831-2840	Gladstone	Mudstone, green, hard. Silty, becoming sandy to base. No flora or fauna recovered.
2840-2842.5		Sandstone, fine- to med.-grained submature litharenite.
2842.5-2846		Sandstone, as above, with scattered mud clasts.
2846-2848.5		Siltstone, argillaceous and arenaceous. No flora recovered.
2848.5-2855		Sandstone, fine to med. mature litharenite. Planar-bedded. A few mud clasts. Erosional basal contact.
2855-2860	Swift	Sandstone, v. fine to fine submature sublitharenite. Flaser bedding, flasers increasing to base; some coarser sand lenses. Abund. siderite.
2860-2887		Ribbon sand, light colour. Lenses of fine sandstone and silt. Slight bioturbation. Fairly sharp basal contact. No flora recovered.
2887-2891		Ribbon sand, dark colour. Sand lenses as above. Moderate bioturbation. Minor pyrite, poss. minor glauconite. DRS flora, no fauna recovered.

Conrad Province #2
1-5-6-15W4
KB 2980; TD 3080
2823-2868 feet

FOOTAGE	FORMATION	DESCRIPTION
2823-2826	Gladstone?	Mudstone, med. grey. Some plant debris. Aptian-Albian (nonmarine) flora recovered.
2826-2834.5		Siltstone, med. grey, hard. Some plant debris, minor calcite.
2834.5-2837		Shale, grey, soft. Thin argillaceous coal seam at top. Aptian-Albian (nonmarine) flora recovered.
2837-2851		Sandstone, poorly-sorted litharenite. Abund. silt. Mostly massive - some low-angle planar cross bedding and poss. lenticular bedding. Abund. siderite; minor plant debris and pyrite.
2851-2854.5		Sandstone - siltstone, med. grey. Fairly massive. Some plant debris. Aptian-Albian (nonmarine) flora recovered.
2854.5-2858	Swift	Shale, dark grey, soft, poor recovery. Upper Jurassic (marine) flora, poss. Lower Cretaceous microfauna recovered.
2858-2868	Rierdon	Shale, grey-green, calcareous, soft. Upper Jurassic (marine) flora, Callovian to Basal Oxfordian fauna recovered.

Dominion Mid-Continent #2
14-24-5-15W4
KB 3068; TD 3235
2985-3076 feet (wireline)

FOOTAGE	FORMATION	DESCRIPTION
2985-2990	Beaver Mines	Mudstone, med. grey, soft.
2990-3028		Mudstone and siltstone, mottled maroon, grey and green. Minor plant debris, waxy surfaces. No flora recovered.
3028-3035		Sandstone, v. fine to fine, irreg. interbedded w. grey shale. Aptian-Albian (nonmarine) flora recovered.
3035-3038		Sandstone, cleaner, sl. coarser, lithic. Some plant debris, minor pyrite.
3038-3048		Mudstone, dark grey, calcareous. Soft, poor recovery. Nondiagnostic flora recovered.
3048-3065		Sandstone, fine-grained submature extrafellitharenite. Massive, w. some shale partings. Some plant material; minor pyrite at base.
3065-3076	Rierdon	Shale, grey-green, calcareous, soft.

CMG Cypress
6-23-7-3W4
KB 4207; TD 5040
4650-4700 feet

FOOTAGE	FORMATION	DESCRIPTION
4650-4655	Swift	Ribbon sand, light colour. Sand content approx 80%; wavy and flaser bedding. Little bioturbation. Basal contact not present.
4655-4685		Ribbon sand, dark colour. Sand content 40-50%; good lenticular bedding. A few large pyrite nodules. Bioturbation moderate; a few churned zones. Basal contact gradational. DRS flora recovered. (See Plate 1d)
4685-4690		Sandstone, fine to med. immature litharenite. Scattered mud flasers. Slightly glauconitic. Sharp basal contact.
4690-4700		Dark ribbon sand; sand lenses somewhat thinner. Minor glauconite. DRS flora recovered.

McColl - Frontenac Union 10B-22
10-22-7-9W4
KB 2785; TD 3295
3029-3130 feet (wireline)

FOOTAGE	FORMATION	DESCRIPTION
3029-3038	Gladstone?	Siltstone, v. argillaceous, red, hard.
3038-3043		Mudstone, med. grey. No flora recovered.
3043-3053.5		Siltstone, w. abund. sand and mud. Generally fining upward; massive. A thin siltstone conglomerate at base.
3053.5-3055	Gladstone	Siltstone to v. fine sandstone, quartzose.
3055-3059		Mudstone, med. grey. Abund. floating sand grains, inc. downward. No flora recovered.
3059-3065		Sandstone, v. fine to fine, v. silty and shaly. Generally fining upward.
3065-3072		Sandstone, v. fine to fine, much cleaner. Massive.
3072-3073.5		Sandstone, fine to med. calcareous extralitharenite. Thin basal conglomerate. Erosional basal contact.
3073.5-3113.5	Rierdon	Shale, grey-green, v. calcareous, hard. Some pyrite; minor macrofossil fragments. Upper Jurassic marine flora recovered.
3113.5-3130	Sawtooth (Shaunavon)	Sandstone, fine to med. calcareous quartzarenite.

GNOL Can Delhi Chinco
1-30-7-14W4
KB 2828; TD 3155
3098-3129 feet

FOOTAGE	FORMATION	DESCRIPTION
3098-3105.5	Cut Bank	Sandstone, poorly-sorted immature litharenite. Fining upward; some cut-and-fill structures. Oil staining.
3105.5-3106		Conglomerate; argillaceous siltstone clasts in extralitharenite matrix. Erosional basal contact.
3106-3107.5		Sandstone, as above.
3107.5-3109		Conglomerate; siltstone clasts, extralitharenite matrix. Minor pyrite.
3109-3112		Sandstone, as above. Some coaly partings; more oil saturation.
3112-3113.5		Conglomerate; v. abund. siltstone clasts.
3113.5-3119		Sandstone, fine to med. mature litharenite. Large-scale low-angle planar cross bedding; cherty laminae. Coaly partings. Oil saturated.
3119-3121		Conglomerate; siltstone clasts, lithic sandstone matrix. Minor pyrite.
3121-3125.5		Sandstone, fine to med. litharenite. Coaly microlenses. Var. calcite cement; var. oil staining. Erosional basal contact.
3125.5-3129	Rierdon	Shale, dark green-grey, hard. Minor pyrite.

CPOG Taber South
8-19-7-16W4
KB 3053; TD 3422
3237-3305 feet

FOOTAGE	FORMATION	DESCRIPTION
3237-3243.5	Gladstone	Siltstone, arenaceous, lt. grey. Some convoluted bedding. No flora recovered.
3243.5-3245		Sandstone, poorly-sorted calcareous sublitharenite. Some pyrite.
3245-3248.5		Siltstone, mottled green and brown, hard. Abund. siderite nodules.
3248.5-3253		Mudstone, green-grey, brown organic staining. Abund. siderite nodules.
3253-3257.5		Siltstone, sandy. Bedding complex - several closely-spaced breaks. Abund. pyrite.
3257.5-3271	Cut Bank	Sandstone, fine to med. immature (sub)litharenite. Large-scale low-angle cross bedding. Some pyrite. Oil saturated.
3271-3275.5		Conglomerate; mud clasts in litharenite matrix. Var. oil staining.
3275.5-3278.5		Sandstone, immature litharenite. Low-angle planar cross bedding. Minor pyrite. Oil saturated.
3278.5-3280		Conglomerate; mud clasts in poorly-sorted litharenite matrix.
3280-3286		Sandstone, fine to med. submature sublitharenite. Large-scale low-angle planar cross bedding. Minor pyrite.
3286-3288.5		Conglomerate; mud clasts in coarse litharenite. Minor pyrite. Oil staining in porous lenses.
3288.5-3291		Sandstone, fine to med. calcareous litharenite. Low-angle cross bedding. Some pyrite. Oil saturated.
3291-3292		Sandstone, v. fine, small-scale trough cross bedding. Abund. pyrite.
3292-3293.5		Shale, green, grey and yellow. Abund. pyrite. No flora recovered.
3293.5-3295		Conglomerate, mud clasts in med. - coarse litharenite matrix.
3295-3298		Sandstone, fine-grained calcareous litharenite. Some pyrite. Erosional basal contact.
3298-3305	Rierdon	Shale, dark grey-green. Minor pyrite.

CMG Cypress
6-1-8-4W4
KB 3732; TD 4460
4052-4101 feet

FOOTAGE	FORMATION	DESCRIPTION
4052-4058	Gladstone	Mudstone, grey-green. Minor plant debris. Lower Cretaceous flora recovered.
4058-4061		Mudstone, med. to dark grey, w. abund. coal. Floating sand grains, inc. to base. Root traces. Lower Cretaceous flora recovered.
4061-4063.5		Mudstone, arenaceous, lt. to med. grey. Abund. coal fragments; some root traces. Grades into sandstone below.
4063.5-4065.5		Sandstone, poorly-sorted immature sublitharenite. Bentonitic clay matrix. Poor recovery.
4065.5-4069		MISSING CORE
4069-4085.5		Sandstone, fine to med. submature sublitharenite. Large-scale low-angle planar cross bedding. Some cut-and-fill structure in upper part. Some coarser lenses and beds.
4085.5-4093.5		Sandstone, as above, grading down to coarser, more mature extralitharenite.
4093.5-4097		Sandstone, med.-grained mature litharenite. Some mud clasts.
4097-4098.5		Sandstone, med. to coarse litharenite. Massive. Erosional basal contact.
4098.5-4099		Ribbon sand, light colour. Sand fraction 80-90%. Slightly bioturbated.
4099-4101	Swift	Ribbon sand, dark colour. Sand 30-40%. Moderate bioturbation. DRS flora recovered.

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McCall - Frontenac British Dominion
14-34-8-7W4
KB 3030; TD 4763
3318-3408 (wireline - poor recovery)

FOOTAGE	FORMATION	DESCRIPTION
3318-3342	Beaver Mines	Sandstone, med.-grained calcareous feldspathic extralitharenite.
3342-3343		Sandstone, v. fine to fine feldspathic litharenite. Some low-angle planar cross bedding.
3343-3393		Sandstone, med. to coarse calcareous feldspathic extralitharenite. Minor pyrite.
3393-3408		Shale, lt.-med. grey, soft. Some plant material. Nondiagnostic flora recovered.

Sun Oil Chinook
7-28-8-14W4
KB 2852; TD 3298
3128-3158 feet

FOOTAGE	FORMATION	DESCRIPTION
3128-3130.5	Beaver Mines	Sandstone, v. fine to fine, w. abund. silt and mud. Somewhat lenticular; similar appearance to ribbon sand. Small-scale cross bedding in lenses. Minor siderite, plant material. Aptian-Albian flora recovered.
3130.5-3140.5		Sandstone, fine to med. calcareous sl. feldspathic litharenite. Massive; poss. some fining upwards.
3140.5-3142		Siltstone, sandy and shaly, with some mud clasts. Some plant debris; minor pyrite and calcite.
3142-3149.5		Sandstone, fine to med. calcareous sl. feldspathic litharenite. Some shale partings. Minor plant debris, pyrite.
3149.5-3156		Sandstone, calcareous, grading down to argillaceous arkosic siltstone. Some shaly partings, small-scale trough cross bedding; becomes sim. to ribbon sand at base. Abund. plant debris; pyrite conc. in one band.
3156-3158	Gladstone? (Calcareous).	Sandstone, silty to v. fine, interbedded with shale in a dark ribbon sand type lithology. Lenticular, slightly bioturbated; abund. plant debris. Poss. Lower Cretaceous Ostracod zone flora, no fauna recovered.

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CPOG South Taber
10-8-8-15W4
KB 2982; TD 3207
3087-3243 feet

FOOTAGE	FORMATION	DESCRIPTION
3087-3082	Beaver Mines	Mudstone, maroon and green, silty. Firmly consolidated.
3082-3089.5		Siltstone, v. poorly-sorted; fining upward.
3089.5-3150		Sandstone, v. fine to med. dolomitic and calcareous extrafellitharenite. Minor plant material and pyrite. V. massive, homogeneous.
3150-3154.5		Sandstone, coarser, more mature litharenite. Shale partings; low-angle planar cross bedding. Minor plant debris and pyrite. Oil saturated. Aptian-Albian flora recovered.
3154.5-3166		Sandstone, v. similar to 3090-3150 interval. Fining upwards.
3166-3178		Sandstone, mature litharenite, v. sim. to 3150-3154.5 interval. Somewhat feldspathic.
3178-3181		Sandstone, v. poorly-sorted, feldspathic, calcareous. Irregularly-bedded. Some calcite-filled fractures.
3181-3189.5	Gladstone (Calcareous)	Siltstone, v. calcareous, tan, v. hard. Interbedded w. lt. grey shale. Minor pyrite. Gradational basal contact. No flora recovered.
3189.5-3204		Siltstone, argillaceous. Bedding irregular.
3204-3210.5	Cut Bank	Sandstone, v. poorly-sorted immature litharenite. Pebbly and argillaceous zones. Minor plant debris and pyrite. Var. oil staining.
3210.5-3225		Siltstone, argillaceous, hard. Some plant material. Irreg. bedded. No flora recovered.
3225-3227		Conglomerate; mud clasts in calcareous sublitharenite matrix. Minor pyrite, plant material. Erosional basal contact.
3227-3243	Rierdon	Shale, grey-green, v. calcareous, hard.

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CPOG Horsefly Lake
12-20-8-16W4
KB 2861; TD 3280
3165-3225 feet

FOOTAGE	FORMATION	DESCRIPTION
3165-3170.5	Cut Bank	Sandstone, v. fine to fine immature sublitharenite. Large-scale planar cross bedding. Argillaceous intervals. Minor pyrite. Oil staining in clean intervals.
3170.5-3171.5		Mudstone, grey-green, silty. Abund. pyrite. No flora recovered.
3171.5-3173		Sandstone, fine immature litharenite. Some mud clasts. Minor pyrite.
3173-3186.5		Sandstone, fine to med. submature to mature litharenite. Num. zones of mud clasts and pebbles. Abund. cut-and-fill. Oil staining.
3186.5-3199		Sandstone, as above, but v. calcareous. Fining upwards. Minor pyrite. Oil saturated. (See Plate 5a)
3199-3225	Rierdon	Shale, dark grey-green, calcareous. Minor pyrite.

CPOG South Taber
10-4-9-16W4
KB 2812; TD 3305
3120-3213 feet

FOOTAGE	FORMATION	DESCRIPTION
3120-3121.5	Beaver Mines	Sandstone, v. fine to fine calcareous feldspathic extralitharenite. Minor carbonaceous material.
3121.5-3131		Siltstone, lenticularly interbedded with mudstone. Some shale partings. One zone of mud clasts. Minor pyrite and plant debris.
3131-3137		Sandstone, as above.
3137-3139	Gladstone (Calcareous)	Siltstone, argillaceous and somewhat arenaceous. Bedding convoluted. Minor plant debris and pyrite. plant debris and pyrite.
3139-3146		Siltstone, interbedded with mudstone; lenticular. Some shale partings. Low-angle cross bedding. Some coaly material, siderite. Lower Cretaceous nonmarine flora recovered.
3146-3158.5		Siltstone - mudstone, as above; more argillaceous, pyritic. No coaly material. Aptian-Albian (nonmarine) flora recovered.
3158.5-3165		Limestone, sl. argillaceous, tan hard. Minor pyrite, fossil fragments.
3165-3175		Siltstone, med. - dark grey, interbedded w. shale. A limestone horizon near top.

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3175-3180.5	Cut Bank	Sandstone, v. fine to fine litharenite. Shale partings. Fines upward. Oil staining.
3180.5-3226		Sandstone, med.-grained mature litharenite. Minor silt fraction. Heterogeneous - num. cut-and-fill structures. Low-angle large-scale planar cross bedding. Oil staining.
3226-3228		Sandstone, not as clean. Some chert pebbles.
3228-3243	Sawtooth?	Sandstone, mature, more quartzose. Friable, poor recovery. Oil saturated.
3243-3244		Conglomerate, sandstone matrix.
3244-3253		Sandstone, fine poorly-consolidated litharenite. Shale partings. Oil staining. Conglomerate w. calcareous cement at base.
3253-3261		Sandstone, fine to med. calcareous litharenite. Planar-bedded; some shale partings. Minor pyrite. Erosional basal contact. No flora recovered.
3261-3273	Rundle	Limestone, coarsely crystalline. Stylolitic.

Chevron Taber
4-18-9-18W4
KB 2763, TD 3276
3170-3218 feet

FOOTAGE	FORMATION	DESCRIPTION
3170-3173.5	Gladstone	Sandstone, med. - coarse mature litharenite. Some mud clasts and pebbles; calcareous at base. Oil staining.
3173.5-3180		Siltstone, grey-green, interbedded w. shale. Laminated and lenticular bedding. Minor pyrite, conc. in coarser lenses. Erosional basal contact.
3180-3181	Cut Bank	Conglomerate, silt and shale clasts, litharenite matrix. Low-angle cross bedding. Oil staining.
3181-3204.5		Sandstone, v. fine to coarse litharenite. Var. maturity and grain size. Good planar low-angle crossbeds. Calcareous at base. Oil staining.
3204.5-3205.5		Siltstone, lt. blue-grey, hard. Minor pyrite, conc. at erosional upper and lower contacts.
3205.5-3208		Sandstone, as above, some shale pebbles. Erosional basal contact.
3208-3218	Rierdon	Shale, green grading down to grey. Minor pyrite, calcite. Jurassic marine palynomorphs recovered.

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Bow Valley Tempest
10-30-8-19W4
KB 2[illegible]20; TD 3781
3555-3638 feet

FOOTAGE	FORMATION	DESCRIPTION
3555-3561	Beaver Mines	Sandstone, silty to fine dolomitic extrafellitharenite. Shaly partings in lower part. Minor plant debris.
3561-3577.5	Gladstone (Calcareous)	Shale, dark grey, silty, hard. Lenses of siltier material; sl. burrowed. Minor siderite. Lower Cretaceous flora recovered.
3577.5-3579		Shale, calcareous, dark.
3579-3585.5		Limestone, sl. argillaceous, yellowish. A few fossil fragments. No flora recovered.
3585.5-3595		Shale, dark grey, calcareous.
3595-3603.5	Gladstone	Siltstone, w. some mudstone. Poss. root zone near base.
3603.5-3606		Sandstone, poorly-sorted submature litharenite. Grades down into silt.
3606-3608		Siltstone, argillaceous. Gradational contacts
3608-3610		Sandstone, silty calcareous litharenite.
3610-3630.5		Siltstone, argillaceous, green-grey grading down to med. grey. Minor pyrite. Aptian-Albian flora recovered.
3630.5-3638	Cut Bank	Sandstone, med.-grained, v. mature litharenite. Some shale partings and pebbly zones. Fining upwards. Minor coaly material.

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Whitehall Barons Taber North
4-27-10-18W4
KB 2620; TD 3331
3209-3254 feet

FOOTAGE	FORMATION	DESCRIPTION
3209-3227	Gladstone (Calcareous)	Shale, silty, med. to dark grey. Minor pyrite, carbonaceous debris. Grades to sandstone below. No flora recovered.
3227-3232.5	Cut Bank	Sandstone, med.-grained calcareous litharenite. Minor pyrite, carbonaceous material.
3232.5-3237		Sandstone, as above, only minor calcite. Some low-angle cross bedding. A few mud clasts near base.
3237-3239		Conglomerate, mud clasts in med.-coarse litharenite matrix.
3239-3241		Siltstone, interbedded w. shale. Thinly-bedded.
3241-3248		Sandstone, fine to v. fine calcareous lithic quartzarenite. Low-angle planar cross-sets; some silty horizons. Minor pyrite.
3248-3254	Rierdon?	Shale, grey-green grading down to med. grey. No flora recovered.

British American Turin
10-7-10-18W4
KB 2785; TD 3820
3418-3466 feet

FOOTAGE	FORMATION	DESCRIPTION
3418-3421.5	Gladstone (Calcareous)	Limestone, tan, interbedded w. v. calcareous shale. Somewhat brecciated.
3421.5-3435		Shale, med.-dark grey, silty. Variably calcareous. Poor recovery. Minor pyrite and carbonaceous debris. No flora recovered.
3435-3450		MISSING CORE
3450-3455	Gladstone	Siltstone, lt. grey, hard. Abund. dissem. pyrite. Coarsens downward into sandstone below.
3455-3457.5	Cut Bank	Sandstone, fine to med. v. calcareous litharenite. Low-angle planar cross bedding; shale partings.
3457.5-3466		Sandstone, med. to fine mature sublitharenite. Low-angle planar cross bedding, minor shale partings. Oil staining.

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Mich-Wis B.A. Turin
10-32-10-19W4
KB 2818; TD 3845
3834-3854 feet

FOOTAGE	FORMATION	DESCRIPTION
3834-3836	Cut Bank	Sandstone, v. fine, interbedded w. silt. Minor pyrite.
3836-3841		Sandstone, v. fine to fine, interbedded w. shaly siltstone. Cut-and-fill structures abundant.
3841-3847.5		Sandstone, v. fine to med. mature litharenite. Low-angle planar cross bedding; fining upwards. Erosional basal contact.
3847.5-3848.5		Conglomerate; chert and siltstone pebbles in med. litharenite matrix.
3848.5-3851		Sandstone, poorly-sorted dolomitic extralitharenite. Scattered chert and siltstone pebbles.
3851-3854	Rierdon	Shale, grey. Poor recovery. Jurassic (marine) flora recovered.

Gridoil Grand Forks
8-31-11-12W4
KB 2475; TD 3053
2845-2875 feet

FOOTAGE	FORMATION	DESCRIPTION
2845-2849	Gladstone	Sandstone, fine, calcareous quartzarenite. Some shale partings. Minor pyrite.
2849-2851		Shale, grey and green, sl. silty. Somewhat bentonitic.
2851-2853	Sawtooth?	Limestone, argillaceous, brown. No flora recovered.
2853-2855		Sandstone, fine to med.-grained, calcareous. Thin (5 cm.) limestone band at base. Erosional contacts.
2855-2858.5		Sandstone, v. fine to fine, interbedded w. siltstone. Some stylolitic limestone lenses. Minor pyrite.
2858.5-2875	Sawtooth	Sandstone, silty to fine mature quartzarenite. Massive, homogeneous. Oil saturated.

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Ashland Grand Forks
14-29-11-13W4
KB 2465; TD [illegible]
2805-3016 feet

FOOTAGE	FORMATION	DESCRIPTION
2805-2880	Gladstone	Sandstone, silty to med.-grained mature quartzarenite. Well-dev. large-scale planar low-angle crossbeds. Minor shale partings; some dirty laminae. Minor pyrite, carbonaceous debris. Calcareous in basal 15 feet. Oil staining.
2880-2885		Siltstone, sandy, w. abund. mud clasts. Some pyrite.
2885-2888	Rierdon?	Shale, grey-green, sl. silty. Some siderite. No flora recovered.
2888-2998	Sawtooth	Sandstone, silty to med. mature quartzarenite. Shaly partings near top; otherwise homogeneous. Oil staining.
2998-3001		Shale, grey-green, silty, hard. Abund. small siderite nodules. No flora recovered.
3001-3016		Sandstone, v. sim. to above sst. interval. Massive, poorly consolidated (poor recovery).

Ashland Taber North
7-15-11-18W4
KB 2584; TD 3295
3198-3248 feet

FOOTAGE	FORMATION	DESCRIPTION
3198-3211	Gladstone (Calcareous)	Siltstone, med. - dark grey, hard. Abund. coaly debris, some siderite. Pyritic bands. Lower Cretaceous (nonmarine) flora recovered.
3211-3213		Siltstone, grey, hard. Grades into limy zone below. Oil staining.
3213-3218		Siltstone, lt. grey, v. calcareous.
3218-3219.5		Siltstone, interbedded lt. grey calcareous and darker non-calc. Minor plant debris.
3219.5-3221	Gladstone	Sandstone, v. fine to fine, calcareous. Coarser lithic grains. Oil saturated.
3221-3248		Siltstone, w. irreg. interbedded bodies of fine silty quartzarenite. Minor plant debris, pyrite, calcite. Oil staining.

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Gascome Retlaw
10-30-11-18W4
KB 2807; TD 3727
3610-3680 feet

FOOTAGE	FORMATION	DESCRIPTION
3610-3617.5	Gladstone (Calcareous)	Shale, somewhat silty, v. calcareous. Minor pyrite, plant fragments. No flora recovered.
3617.5-3629		Shale, sl. silty, lt. grey. Some calcite-filled fractures. Minor pyrite, plant material. No flora recovered.
3629-3631		Sandstone, v. fine to fine, lithic, calcareous. Some pyrite, minor plant debris.
3631-3633.5		Siltstone, dark grey, hard, calcareous. Minor plant debris and pyrite.
3633.5-3635.5		Sandstone, poorly-sorted immature litharenite.
3635.5-3654		Shale, dark grey, somewhat calcareous. Some macrofossils, calc. nodules; shell bed at 3637. Dissem. and nodular pyrite, some plant debris. Aptian-Albian (nonmarine) flora recovered.
3654-3659.5	Cut Bank	Sandstone, fine-med. mature litharenite. Some thin coaly shale beds, low-angle planar cross bedding. Var. calcite. Oil staining.
3659.5-3671.5	Rierdon	Shale, dark grey-green, hard, somewhat calcareous. Some excellent macrofossils, esp. belemnites.
3671.5-3680	Rundle	Limestone, crystalline, with chert nodules. Oil staining. No flora recovered.

Western Turin
11-10-11-18W4
KB 2783; TD 3630
3558-3596 feet

FOOTAGE	FORMATION	DESCRIPTION
3558-3563	Cut Bank	Sandstone, v. fine to med. mature sublitharenite. Fining upwards.
3563-3584.5		Conglomerate, shale and chert pebbles in poorly-sorted litharenite matrix. Minor pyrite, carbonaceous debris. Erosional basal contact.
3584.5-3596	Rierdon	Shale, grey-green, calcareous. Harder, more calc. to base. Jurassic(?) marine flora, Upper Jurassic(?) fauna recovered.

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Westcoast Grand Forks
8-5-12-12W4
KB 2453; TD 3105
2820-2850 feet

FOOTAGE	FORMATION	DESCRIPTION
2820-2838	Beaver Mines	Sandstone, v. fine to fine immature feldspathic extralitharenite. Homogeneous, fairly massive. Minor carbonaceous material.
2838-2850		Sandstone, v. fine to fine, v. calcareous extrafellitharenite. Shale partings, some laminations in lower part.

B.A. United Prod. Grand Forks
7-30-12-13W4
KB 2539; TD 3200
: 45-3091 feet

FOOTAGE	FORMATION	DESCRIPTION
3045-3045.5	Sawtooth	Limestone, hard crystalline. Some floating sand grains. Minor pyrite, carbonaceous debris.
3045.5-3055.5		Sandstone, fine submature quartzarenite. Minor feldspar. Contorted sand-shale interbeds in central part. Oil saturated.
3055.5-3058		Siltstone, lenticularly-bedded with shale, grey-green. Minor pyrite, mica.
3058-3065.5		Sandstone, v. fine to fine, fining upward to silt at top. Thinly bedded. A few scattered pebbles. Oil staining.
3065.5-3068.5		Shale, grey-green, hard. V. finely dissem. pyrite. No flora recovered.
3068.5-3091	Rundle	Limestone, crystalline, hard. Some contorted shale interbeds, stylolitic to base.

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Sun Retlaw
12-21-12-18W4
KB 2728; TD 3660
3550-3626 feet

FOOTAGE	FORMATION	DESCRIPTION
3550-3557.5	Gladstone (Calcareous)	Sandstone, poorly-sorted mature sublitharenite.
3557.5-3560.5		Sandstone, as above, calcareous. Thinly-bedded; some low-angle planar cross bedding. Fining upward, more lithic to base. Oil staining in top part.
3560.5-3570		Siltstone, argillaceous, v. calcareous. Minor pyrite, plant debris. Aptian-Albian (nonmarine) flora recovered.
3570-3575		Limestone, somewhat argillaceous. Abund. large shell fragments.
3575-3586		Shale, med.-dark grey, hard. Sl. silty. Minor carbonaceous debris, siderite. No flora recovered.
3586-3590	Gladstone	Sandstone, fine, lithic, friable. Gradational contacts. Oil saturated.
3590-3593		Siltstone, poorly-sorted. Root zone, minor carbonaceous debris.
3593-3597.5		Mudstone, dark grey, silty. Some plant debris, pyrite.
3597.5-3620		Siltstone and mudstone, intricately interbedded. A few beds of oil-stained sandstone. Convoluted bedding in lower part. Some plant debris; minor pyrite.
3620-3626	Cut Bank	Sandstone, med.-coarse, supermature sublitharenite. Coal partings and microlenses. Oil staining.

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Cairn CNW Czar Retlaw
3-20-12-19W4
KB 2785, TD 3835
3715-3761 feet

FOOTAGE	FORMATION	DESCRIPTION
3715-3718.5	Gladstone (Calcareous)	Siltstone, argillaceous, hard. Limy concretions in lower part. Minor pyrite and carbonaceous debris.
3718.5-3719.5	Gladstone	Conglomerate; chert and siltstone pebbles, carbonaceous debris.
3719.5-3722.5		Sandstone, poorly-sorted immature extralitharenite. Oil staining.
3722.5-3724		Siltstone, poorly-sorted, med. grey. Minor pyrite, carbonaceous debris.
3724-3725.5		Sandstone, as above. Somewhat less lithic.
3725.5-3726		Siltstone; some floating sand grains.
3726-3733		Sandstone, poorly-sorted immature sublitharenite. Fines upward; sorting improves to base. Planar-bedded. Fairly abund. pyrite.
3733-3738		Mudstone, grey-green. Abund. dissem. pyrite.
3738-3740.5		Mudstone, yellow, hard. Some siderite nodules.
3740.5-3749	Cut Bank	Sandstone, v. fine to fine mature litharenite. Low-angle planar cross bedding. Pebbly zone at base. Minor pyrite. Oil staining in top half.
3749-3751.5		Sandstone, as above. More heterogeneous; cut-and-fill structures.
3751.5-3754		Conglomerate; chert and siltstone pebbles in med.-coarse lithic matrix.
3754-3760.5		Sandstone, med. - coarse mature litharenite. Abund. conglomeratic zones; pebbles lie on scour surfaces. Well-devel. planar crossbeds. Calcareous to base. Erosional basal contact.
3760.5-3761	Rierdon	Shale, med.-dark grey, hard. Minor pyrite. Jurassic flora recovered.

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Texaco Enchant C-1
3-34-13-17W4
KB 2638; TD 4886
3310-3370 feet

FOOTAGE	FORMATION	DESCRIPTION
3310-3316.5	Gladstone	Sandstone, poorly-sorted silty quartzarenite. Massive. Abund. carbonaceous debris.
3316.5-3322.5		Mudstone, silty, w. coarser silt bodies; grading down to dark shale. Aptian-Albian (nonmarine) flora recovered.
3322.5-3324		Sandstone, poorly-sorted immature sublitharenite.
3324-3330		MISSING CORE
3330-3331.5		Mudstone, dark grey. Coarser silt lenses at top; hematitic bands and coaly debris near base. Aptian-Albian (nonmarine) flora recovered.
3331.5-3340		Sandstone, v. fine to med.-grained, lithic. Contorted shale partings. Minor carbonaceous debris, pyrite.
3340-3350		MISSING CORE
3350-3352		Siltstone, interbedded w. shale. Coarser silt lenses, small-scale trough cross bedding.
3352-3357		Mudstone, w. scattered silt lenses. Some siderite, carbonaceous material. Aptian-Albian (nonmarine) flora recovered.
3357-3362		MISSING CORE
3362-3363		Mudstone, as above.
3363-3365		Sandstone, v. fine to fine, w. silty lenses, convoluted bedding. Some pyrite, carbonaceous debris.
3365-3370	Rierdon	Shale, grey-green. V. calcareous, w. argillaceous limestone bands. Upper Jurassic (marine) flora recovered.

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Richfield Oil Corp. East Alder
12-10-15-10W4
KB 2471; TD 3134
3080-3114 feet

FOOTAGE	FORMATION	DESCRIPTION
3080-3082	Gladstone	Mudstone, light grey. Soft, crumbly, abund. swelling clay. Some large pyrite bodies.
3082-3086		Siltstone to fine sandstone, coarsens to base. Contorted small-scale trough cross bedding and shale laminations. Small-scale soft-sediment faulting. Abund. pyrite.
3086-3101		Sandstone, fine - med. variably calcareous litharenite. Grades down from siltstone above. Fairly massive. Oil staining.
3101-3114		Mudstone, green, with very abund. Rundle carbonate clasts. Chert pebbles, fossil debris (esp. crinoids) most common. Could be assigned to Deville Member.

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APPENDIX B

Formation Tops

This appendix lists depths (in feet) at which formation tops are encountered in the 535 boreholes examined in this thesis. Locations are given using the Dominion Land Survey (DLS) system in Alberta and the equivalent American system in Montana. Zeroes signify that the formation top could not be determined; the letter 'E' and the letters 'EEEE' indicate that the formation is not present.

The following abbreviations are used:

KB:	Kelly Bushing
KFS:	Base of Fish Scales Zone
GLAD:	Gladstone Formation
CUTB:	Cut Bank Formation
SRS:	Ribbon sand member, Swift Formation
SS:	Shale member, Swift Formation
JR:	Rierdon Formation
JSTH:	Pre-Upper Jurassic strata (Sawtooth/Shaunavon/Mississippian)

LOCATION	KB	KFS	GLAD	CUTB	SRS	SS	JR	JSTH
NENE 23 30N 9E	2963	1750	2750	2660E	2660	2945	3005	3142
NWNE 35 30N 8E	2934	1808	2600	2718E	2718	2787	2847	2880
SENE 15 30N 7E	3038	1842	2578	2682E	2682	2753	2786	2821
NWNE 26 30N 3E	0000	882	1818	2012E	2012	2093	2108	2228
SENW 23 30N 1E	3292	574	1695	1769E	1769	1826	1854	1957
SWSW 26 30N 1W	3565	730	1920	1983E	1983	2048	2082	2187
NWSE 34 30N 3W	3736	1056	2248	2308E	2308	2372	2383	2503
NWSE 14 30N 4W	3729	1336	2373	2469E	2469	2547E	2547	2673
NESE 18 30N 5W	3742	1707	2792	2904	2931E	2931E	2931	3084
SESE 30 30N 6W	3786	2239	3299	3447	3487E	3487E	3487	3825
NWNW 16 30N 7W	4032	2940	4120	4245	4280E	4280	4328	4422
NENW 33 30N 8W	4136	3853	4747	4903	4933E	4933	4986	5088
SWSW 35 31N 12E	2836	2130	3119	3220E	3220	3258	3343	3516
SWNE 32 31N 9E	3131	1927	2979	3047E	3047	3120	3189	3311
SESW 5 31N 7E	3220	0000	2743	2858E	2858	2890	2983	3098
SESE 33 31N 4E	3022	892	1941	2028E	2028	2086	2115	2238
NENE 14 31N 2E	3207	520	1676	1734E	1734	1812	1826	1838
NWNW 8 31N 1W	3424	711	1540	1640E	1640	1724E	1724	1854
NWNE 21 31N 2W	3356	787	1685	1780E	1780	1858E	1858	1985
NESE 19 31N 3W	3453	857	2111	2189E	2189	2257E	2257	2381

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LOCATION	KB	KFS	GLAD	CUTB	SRS	SS	JR	JSTH
NWNE 18 31N 4W	3248	0000	2043	2188	2180E	2180E	2180	2309
NESW 9 31N 5W	3555	1730	2890	2812	2840E	2840E	2840	2958
SENE 8 31N 8W	3789	2237	3290	3430	3471E	3471	3512	0000
SWSE 10 31N 8W	3787	2128	3144	0000	3328E	3328E	3328	0000
SESW 13 31N 6W	3730	1957	2972	3079	3128E	3128E	3128	3257
NWSW 14 31N 8W	3778	2072	3090	3265	3280E	3280E	3280	3382
NENE 13 31N 7W	4021	2708	3738	3900	3921E	3921	3948	4080
NWSW 6 31N 8W	3885	3772	4928	5080	5100E	5100	5144	5280
SESE 18 32N 11E	2878	2178	3183	3280E	3280	3380	3397	3585
NENE 17 32N 9E	3232	2239	3236	3335E	3335	3400	3449	3505
SWSW 12 32N 8E	3239	1733	2739	2854E	2854	2896	2969	3078
NENE 23 32N 6E	3231	1702	2701	2794E	2794	2850	2828	3041
NWSW 4 32N 5E	3305	1341	2385	2438E	2438	2515	2558	2859
SWNE 14 32N 4E	3383	1247	2282	2345E	2345	2432	2445	2566
SESE 11 32N 3E	3298	937	1980	2045E	2045	2100	2109	2233
NENE 23 32N 2E	3124	482	1534	1640E	1640	1660	1670	1781
SESW 19 32N 1W	3489	711	1528	1645E	1645	1728E	1725	1859
NESW 16 32N 2W	3308	890	1382	1489E	1489	1589E	1589	0000
SESE 29 32N 2W	3444	850	1640	1760E	1760	1860E	1860	1981
SESW 11 32N 3W	3497	781	1728	1818E	1818	1898	1908	2030
NWNW 15 32N 3W	3547	936	1870	1990E	1990	2078E	2078	2198
SENE 25 32N 4W	3718	1325	2204	2334E	2334	2423E	2423	2544

SENE 15 32N 5W	3839	1728	2872	2812	2844E	2844E	2844	2970
NESE 21 32N 5W	3838	0000	2578	2712	2744E	2744	2770	0000
NESE 30 32N 5W	3850	0000	2778	2884	2932E	2932	0000	0000
SWNW 14 32N 6W	3847	2071	3108	3282	3301E	3301	3308	3398
SWNW 19 32N 8W	4058	2814	3688	3835	3874E	3874	3888	3982
SWSW 33 32N 8W	3542	1990	3077	3185	3221E	3221	3248	0000
NESW 28 32N 8W	3904	3180	4338	4470	4501E	4501	4527	4838
SENW 21 33N 12E	2880	2378	3388	3422E	3422	3478	3584	3741
NWSE 6 33N 11E	2899	2190	3158	3234E	3234	3293	3387	3538
NWNW 16 33N 9E	3123	2322	3342	3422E	3422	3547	3615	3798
SWNW 31 33N 7E	3475	2015	3028	3091E	3091	3188	3224	3352
SWSW 5 33N 6E	3391	1860	2721	2758E	2758	2830	2870	2981
SWSE 14 33N 5E	3302	1440	2492	2504E	2504	2586	2621	2727
SESW 13 33N 4E	3419	0000	2145	2182E	2182	2262	2299	2398
NWSE 13 33N 4E	3434	1155	2203	2230E	2230	2319	2357	2453
SESE 1[illegible] 33N 3E	3549	1205	2268	2350E	2350E	2350	2391	2600
NWNW 1[illegible] 33N 2E	3243	654	1518	1585E	1585	1662	1685	1798
SWNW 14 33N 1E	3377	417	1421	1478E	1478	1552E	1552	1700
NWSE 1[illegible] 33N 2W	3581	450	1415	1488E	1488	1585E	1585	1704
SENW [illegible] 33N 4W	3514	1057	1950	2050	2090E	2090E	2090	2203
SWSE 13 33N 4W	3361	739	1587	1692E	1692	1782E	1782	1803
SWNW 17 33N 5W	3846	1609	2787	2956	2966E	2966E	2966	0000
NWNE 35 33N 5W	3874	1728	2850	2777	2830E	2830E	2830	2915

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LOCATION	.KB	KPS	GLAD	CUTB	SRS	SS	JR	JSTH
SENW 32 33N 8W	3722	2095	3134	3282	3334E	3334E	3334	3432
SWNW 36 33N 8W	3783	2035	3056	3221	3242E	3242	3282	0000
SENW 2 33N 9W	4071	4015	5147	5303	5343E	5343	5378	5505
NWSE 7 34N 11E	2983	2365	3392E	3392E	3392	3453	3535	3898
NWSE 20 34N 11E	2930	2334	3321	3366E	3366	3412	3498	3871
NENE 21 34N 10E	2953	2177	3148	3235E	3235	3290	3384	3525
SWSW 26 34N 9E	3037	2088	3050	3130E	3130	3184	3250	3410
SENW 5 34N 8E	3204	1960	2852	2885E	2885	3114E	3114	3242
SWSE 8 34N 7E	3394	1934	2948	2955E	2955	3045	3078	3210
SESE 20 34N 6E	3420	1894	2738	2773E	2773	2824	2880	2880
NWSE 8 34N 5E	3507	1598	2640	2730E	2730E	2730	2784	2877
NESW 9 34N 4E	3655	1303	2380	2438E	2438E	2438	2478	0000
NENE 12 34N 3E	3655	1348	2376	2478E	2478E	2478	2499	0000
SESE 12 34N 3E	3609	1290	2328	2431E	2431E	2431	2452	0000
SESE 8 34N 2E	3404	590	1684	1730E	1730	1818	1840	1947
NWNW 15 34N 1E	3337	390	1356	1422E	1422	1509	1532	0000
SWSW 21 34N 1E	3477	456	1436	1508E	1508	1600E	1600	1714
NENE 30 34N 1W	3583	0000	1082	1118E	1118	1204E	1204	1328
NENW 15 34N 2W	3438	232	1210	1266E	1266	1347E	1347	1461
SWSE 33 34N 3W	3327	488	1295	1410E	1410	1498E	1498	1614
SESE 14 34N 4W	3427	590	1522	1643E	1643	1730	1748	1850
NENE 6 34N 5W	3861	1491	2533	2656	2704E	2704E	2704	2762
NWNW 13 34N 5W	3990	1420	2481	2598	2618E	2618E	2618	0000
NESE 23 34N 6W	3769	1784	2722	2848	2896E	2896E	2896	0000
NWNW 35 34N 6W	3751	1870	2812	2918	2982E	2982E	2982	3078
SENW 2 34N 7W	3828	2218	3284	3367	3442E	3442	3460	3537
SWSW 28 34N 8W	3894	3396	4482	4580	4710E	4710	4728	4843
SESE 26 34N 9W	3982	3624	4914	5094	5145E	5145	5204	5306
SWSW 18 35N 11E	2858	2198	3203	3221E	3221	3270	3348	3611
NWNW 2 35N 10E	2909	2281	3233	3272E	3272	3310	3399	3556
NWSE 7 35N 9E	3033	2022	3031	3081E	3081	3188E	3188	3337
SWSW 21 35N 9E	3015	2014	3003	3055E	3055	3132	3180	3327
NWSE 13 35N 6E	3422	1826	2951	2970E	2970	3044	3078	3218
SWSW 12 35N 5E	3880	1640	2858	2892E	2892	2943	2972	3101
NESE 13 35N 4E	3860	1530	2542	2573E	2573	2617	2651	2811
SESW 17 35N 3E	3745	1300	2351	2428E	2428E	2428	2455	2593
NESW 5 35N 2E	3820	1082	2127	2140E	2140	2203	2230	2356
NESE 20 35N 1E	3824	777	1761	1877E	1877E	1877	1901	2000
SWSW 2 35N 1W	3677	814	1788	1800E	1800	1808E	1808	2018
SENW 31 35N 2W	3354	262	1209	1282E	1282	1370E	1370	1475
NENE 36 35N 2W	3512	420	1338	1366E	1366	1426	1448	0000
SWSE 27 35N 3W	3384	380	1312	1392E	1392	1475E	1475	1590
NENE 32 35N 4W	3612	925	1906	2010E	2010	2078	2078	2188
NENW 28 35N 5W	3981	1511	2555	2672	2718E	2718E	2718	2794
SENW 31 35N 6W	3844	2080	3030	3184	3211E	3211	3218	3313

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LOCATION	KB	KFS	GLAD	CUTB	SRS	SS	JR	JSTH
SWNE 36 35N 7W	3874	2182	3170	3312	3350E	3350	3357	0000
SWNE 12 36N 12E	2781	2483	3422E	3422E	3422	3480	3561	3730
SWSW 1 36N 10E	2880	2270	3272	3285E	3285	3348	3399	3584
SENW 36 36N 9E	3008	2190	3172	3228E	3228	3258	3337	3498
NE 10 36N 8E	3104	2036	3041	3083E	3083	3185	3215	3385
SESE 7 36N 8E	3795	0000	2308	2378E	2378	2420	2450	0000
SESE 13 36N 5E	4153	1200	2128	2180E	2180	2270E	2270	2428
SWNE 25 36N 5E	4031	1288	2287	2278E	2278	2373E	2373	2518
NESW 6 36N 4E	3876	1483	2505	2552E	2552	2590E	2590	0000
SENW 8 36N 4E	4071	1370	2384	2397E	2397	2410	2437	2592
NESW 20 36N 4E	4282	1380	2335	2407E	2407E	2407	2428	2580
SWNW 33 36N 4E	4282	950	1887	1936E	1936	1982	1976	2108
NWNW 7 36N 3E	4185	1723	2824	2906E	2906E	2906	2921	0000
SWNE 11 36N 2E	4089	1807	2789	2848E	2848E	2848	2874	3022
NENW 3 36N 1E	4236	878	1808	1848E	1848	2005	2027	2182
SESE 8 36N 1E	3782	804	1777	1810E	1810	1882	1904	2017
SWSW 5 36N 1W	3507	947	1801	1822E	1822	2042E	2042	2146
SWSW 14 36N 2W	3378	682	1652	1683E	1683	1772E	1772	0000
NE 35 36N 2W	3504	804	1588	1626E	1626	1713E	1713	1822
SENE 17 36N 3W	3588	900	1905	1962E	1962	2038E	2038	2148
NESW 29 36N 4W	4138	1683	2584	2672	2718E	2718E	2718	2787
NESW 2 36N 5W	3838	1507	2508	2631	2680E	2680E	2680	2738
SWSE 7 36N 5W	3988	1600	2798	2826	2989E	2989E	2989	3088
NWSW 11 36N 5W	3990	1503	2485	2624	2678E	2678E	2678	2740
SWSE 4 36N 6W	4085	2084	3114	3226	3268E	3268E	3268	3351
NWSW 3 36N 7W	4158	2402	3498	3608	3658E	3658	3652	3757
SESW 10 36N 8W	4286	3214	4271	4408	4478E	4478	4498	4592
SWSE 32 37N 12E	2781	2373	3298	3312E	3312	3370	3470	3633
NENE 18 37N 11E	2912	2374	3323	3334E	3334E	3374	3488	3638
NESW 20 37N 10E	2908	2228	3188	3238E	3238	3311	3367	3624
SENW 30 37N 10E	2836	2214	3288	3301E	3301	3364E	3364	3613
NWSE 14 37N 9E	2980	2208	3173	3212E	3212	3284	3308	3470
NWNE 28 37N 8E	3118	2145	3128	3174E	3174	3258	3290	3450
NWNW 10 37N 7E	3390	2277	3241	3320E	3320	3390	3408	3588
SWSW 23 37N 6E	3341	0000	2954	3036E	3036	3133E	3133	3333
NENE 30 37N 6E	3370	1857	2817	2875E	2875	2950	2965	3158
NENE 6 37N 5E	3623	1941	2924E	2924E	2924	3043E	3043	0000
SENE 8 37N 5E	3724	1883	2830	2847E	2847	2960E	2960	0000
NWSW 9 37N 5E	3728	1830	2795	2808E	2808	2913E	2913	0000
SWSE 9 37N 5E	3699	1858	2824E	2824E	2824	2921	2927	0000
SWNW 10 37N 5E	3539	0000	2845E	2845E	2845	0000	0000	0000
NWSE 30 37N 5E	4190	1732	2690	2720E	2720	2772	2794	2870
NENE 8 37N 4E	3645	1572	2583	2610E	2610	2667	2685	0000
NWNW 4 37N 3E	3667	1777	2807	2915E	2915E	2915E	2915	3036
SENE 15 37N 3E	3858	1750	2802	2848E	2848	0000	0000	0000

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LOCATION	KB	KFS	GLAD	CUTB	SRS	SS	JR	JSTH
NWNW 9 37N 2E	3647	1444	2455	2508E	2508E	2508	2542	2690
SESE 23 37N 2E	3711	1533	2592	2627E	2627	2652	2669	0000
NWNE 26 37N 2E	3740	1526	2526	2618E	2618	2650	2665	0000
SESE 35 37N 2E	3753	0000	2436	2503E	2503	2516	2537	0000
NENW 2 37N 1E	4016	954	1924	1952E	1952	1982	2013	2136
SESE 4 37N 1W	3586	1425	2392	2437E	2437	2533	2550	2666
SESW 14 37N 2W	3389	1057	2047	2055E	2075	2172E	2172	2264
NESE 6 37N 3W	3523	1340	2345	2384E	2418	2452E	2452	2528
SESW 3 37N 4W	3800	0000	2428	2622	2673E	2673E	2673	0000
SENW 9 37N 4W	3704	0000	2520	2633	2698E	2698E	2698	0000
NWNW 17 37N 4W	3605	0000	2746	2834	2922E	2922E	2922	0000
NWNW 18 37N 4W	3736	0000	2592	2732	2771E	2771E	2771	2811
SENW 10 37N 5W	3793	0000	0000	2697	2773E	2773E	2773	0000
SWNW 11 37N 5W	3793	1550	2537	2653	2710E	2710E	2710	2756
NENW 35 37N 5W	3645	1452	2466	2545	2622E	2622E	2622	2672
SWSE 11 37N 6W	4147	2285	3083	3226	3280E	3280E	3280	3346
SENE 25 37N 6W	4114	2000	3010	3132	3187E	3187E	3187	3286
SESE 16 37N 7W	4290	2524	3617	3730	3767E	3767	3776	3863
SENE 8 37N 8W	3998	3073	4145	4274	4310E	4310	4326	4422
10 28 1 1W4	2846	2495	3424	3440E	3440	3466	3582	3731
6 2 1 3W4	2871	2381	3408	3429E	3429	3510	3561	3734
6 16 1 4W4	2818	2208	3143	3182E	3182	3240	3290	3456

16 20 1 5W4	3188	2208	3186	3208E	3208	3266	3311	3474
7 14 1 6W4	3278	2316	3261	3302E	3302	3360	3408	3581
10 18 1 7W4	3482	2323	3256	3327E	3327	3383E	3383	3556
5 17 1 8W4	3528	1948	2861	2902E	2902	2976	2992	3182
11 22 1 8W4	3395	2188	3070	3148E	3148	3213	3222	3400
6 28 1 8W4	3362	2120	2984	3068E	3068	3136	3160	3303
7 28 1 8W4	3404	2136	3010	3103E	3103	3181	3174	0000
2 4 1 9W4	3616	1751	2690	2712E	2712	2773	2791	2852
16 29 1 9W4	3408	2010	2800	2884E	2884	0000	3083	3185
6 23 1 10W4	3325	1980	2990	3000E	3000	3054	3071	3233
6 35 1 10W4	3281	1796	2773	2776E	2776	2838	2863	3001
6 36 1 10W4	3280	1882	2778	2802E	2802	2868	2886	0000
6 1 1 11W4	3723	1876	2808	3017E	3017E	3017E	3017	3146
7 30 1 11W4	3215	1480	2495	2590E	2590E	2590E	2590	2708
7 16 1 12W4	3531	1444	2428	2453E	2453	2498	2524	2636
3 13 1 13W4	3530	1584	2580E	2580E	2580	0000	0000	0000
7 16 1 14W4	3488	1386	2372	2444E	2444	2491E	2491	2870
11 23 1 15W4	3416	1354	2334	2442E	2442E	2442	2479	2560
10 1 1 16W4	3506	1365	2346	2452E	2452E	2452E	2452	2525
4 2 1 16W4	3613	1332	2326	2396	2406E	2406	2420	2500
7 9 1 16W4	3566	1432	2456	2510	2566E	2566E	2566	2597
9 18 1 18W4	3555	1510	2485	2622	2656E	2656E	2658	2689
10 22 1 18W4	3556	1574	2557	2674	2694E	2694E	2694	2768

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LOCATION	KB	KPS	GLAD	CUTB	SRS	SS	JR	JSTH
3 33 1 18W4	3475	1526	0000	2616	2627E	2627E	2627	2694
10 1 1 17W4	3640	1567	2535	2684	2718E	2718E	2718	2757
2 4 1 17W4	3609	1595	2636	2756	2808E	2808E	2808	2850
16 16 1 17W4	3915	1626	2852	2876	3012E	3012E	3012	3048
6 36 1 17W4	3884	0000	2765	2853	2833E	2933E	2933	2962
11 5 1 18W4	4113	2190	3199	3298	3325	3347E	3347	3418
3 19 1 18W4	3912	2140	3189	3280	3316E	3316E	3316	3385
10 21 1 18W4	3955	2212	3214	3314	3380E	3380E	3380	3434
14 33 1 19W4	3881	2390	3419	3502	3558E	3558E	3558	3641
11 10 1 20W4	3839	2445	3555	3636	3674E	3674	3686	3792
1 35 1 20W4	3915	2673	3750	3855	3882E	3882E	3882	3992
10 8 2 1W4	2812	2570	3503	3512E	3512	3538	3803	3772
8 25 2 1W4	2837	2456	3397E	3397E	3397	3450	3522	3689
10 20 2 2W4	2964	2501	3460	3460E	3460	3509	3550	3714
11 7 2 3W4	2995	2384	3327	3363E	3363	3390	3437	3602
10 31 2 3W4	3223	2622	3487	3561E	3561	3610	3649	3802
11 15 2 5W4	3110	2288	3189	3239E	3239	3320	3337	3484
10 27 2 5W4	3060	2260	3124	3203E	3203	3245	3283	3429
6 7 2 6W4	3214	2209	3134	3182E	3182	3248	3288	3449
11 32 2 6W4	3282	2337	3280	3320E	3320	3360	3390	3554
10 34 2 7W4	3080	2050	2867	3005E	3005	3098E	3098	3271
7 29 2 8W4	3002	1688	2740	2798E	2798	2891E	2891	3035
6 31 2 8W4	2850	1694	2572	2612E	2612	2693E	2693	2840
11 35 2 9W4	2947	1750	2637	2720E	2720	2758	2770	0000
14 25 2 10W4	2891	1618	2553	2583E	2583	2618	2635	2768
11 34 2 12W4	3148	1878	2677	2732E	2732E	2732E	2732	2842
10 29 2 13W4	3129	1505	2600	2660E	2660E	2660	2683	2889
2 8 2 16W4	3433	0000	2557	2830E	2830	2843E	2843	2717
7 10 2 16W4	3361	1483	2487	2558E	2558	2571E	2571	2652
6 28 2 16W4	3468	1783	2750	2774	2798	2828E	2828	2912
7 9 2 17W4	3700	1844	2851	2953	3012E	3012E	3012	3050
12 36 2 18W4	3858	2220	3244	3336	3364E	3364E	3364	3422
13 3 2 19W4	3947	2450	3482	3554	3620E	3620E	3620	3703
10 17 3 1W4	3261	2890	3838	3852E	3852	3873	3927	4083
15 22 3 3W4	3175	2652	3574	3594E	3594	3635	3669	3834
12 9 3 4W4	3270	2600	3478	3524E	3524	3580	3625	3780
11 3 3 5W4	3082	2317	3174	3218E	3218	3342E	3342	3484
13 20 3 5W4	3171	2385	3292	3353E	3353	3367	3400	3553
6 15 3 6W4	2984	2115	3058	3092E	3092	3140	3166	3342
10 20 3 7W4	2930	1917	2836	2882E	2882	2933	2956	3136
10 28 3 7W4	2924	1960	2877	2917E	2917	2970	2989	3171
11 4 3 8W4	2998	1810	2758	2808E	2808	2864	2882	3035
7 17 3 8W4	2995	1860	2762	2818E	2818	2874	2883	3046
8 22 3 8W4	2967	1883	0000	0000E	0000	2919E	2919	3066
6 11 3 9W4	2943	1780	2676	2747E	2747	2768	2784	0000

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LOCATION	KB	KFS	GLAD	CUTB	SRS	SS	JR	JSTH
6 18 3 9W4	3013	1819	2727	2758E	2758	2782	2824	2984
7 27 3 10W4	3088	1900	2832	2900E	2900E	2900	2924	3084
6 24 3 12W4	3263	1917	2910	2993E	2993E	2993E	2993	3052
10 22 3 13W4	3024	1594	2563	2619E	2619E	2619E	2619	2719
7 25 3 14W4	3082	1802	2567	2590E	2590	2612	2647	2730
11 12 3 17W4	3498	1925	2930	2988	3045E	3045E	3045	3093
1 13 3 17W4	3458	1900	2877	2958	3000E	3000E	3000	3055
7 14 3 20W4	4225	3070	4132	4190	4213E	4213	4221	4316
14 2 4 2W4	3256	2858	3798E	3798E	3798E	3798	3861	4023
7 5 4 4W4	3390	2738	3562E	3562E	3562	3711	3769	3822
6 22 4 4W4	3184	2550	3482	3462E	3462	3580E	3580	3728
10 30 4 4W4	3197	2554	3475E	3475E	3475	3572E	3572	3730
5 2 4 7W4	2828	1918	2833	2889E	2889	2938	2948	3138
7 5 4 7W4	2819	1837	2741	2788E	2788	2834	2851	3016
8 7 4 7W4	2875	1814	2808	2854E	2854	2902	2922	3111
10 7 4 7W4	2851	1797	2803	2843E	2843	2893	2920	0000
8 1 4 9W4	2979	1880	2825	2858E	2858	2902	2923	3065
10 8 4 9W4	3041	1930	2916	2938E	2938	2960	2975	3108
11 5 4 10W4	3130	1922	2836	2902E	2902	2922	2938	3080
5 19 4 10W4	3090	1931	2864	2921E	2921E	2921	2940	3082
14 33 4 11W4	3046	1905	2870	2960E	2960E	2960E	2960	3000
14 21 4 13W4	3058	1790	2764	2808E	2808E	2808E	2806	2931
1 10 4 14W4	3088	1683	2643	2690E	2690	2713	2740	2822
12 7 4 15W4	3179	1760	2712	2798E	2798	2842	2846	2931
15 15 4 15W4	3161	1824	2819	2828E	2828	2846	2869	2955
12 36 4 15W4	3101	1840	2834	2840E	2840	2854	2871	2920
13 20 4 16W4	3362	2060	3090	3170E	3170E	3170E	3170	3270
16 13 4 17W4	3325	2006	3050	3085	3108E	3108	3112	3188
10 28 4 17W4	3298	2187	3188	3283	3318E	3318E	3318	3365
5 30 4 18W4	3448	2258	3260	3338	3391E	3391E	3391	3448
4 9 4 19W4	4127	3128	4188	4231	4267E	4267	4287	4388
10 12 4 20W4	4113	3094	4166	4213	4238E	4238E	4236	4338
11 11 5 1W4	3353	3042	4012E	4012E	4012E	4012	4040	4190
3 12 5 3W4	3615	3123	4072E	4072E	4072	4098	4124	4288
6 17 5 3W4	3683	3150	4074E	4074E	4074	4150E	4150	4308
5 31 5 3W4	3839	3287	4203E	4203E	4203	4264	4290	4450
10 3 5 4W4	3483	2894	3787E	3787E	3797	3914E	3914	4072
10 4 5 4W4	3385	2776	3704E	3704E	3704	3805E	3805	3984
4 32 5 4W4	3841	3025	3955	3988E	3988	4010	4029	4188
14 32 5 4W4	3769	3150	4090	4135E	4136E	4136	4161	4303
2 14 5 5W4	3427	2775	3737E	3737E	3737	3785	3800	0000
7 15 5 5W4	3337	2866	3632E	3632E	3632	3686	3682	3848
6 21 5 5W4	3194	2610	3486E	3486E	3486	3514	3530	3688
2 23 5 5W4	3376	2734	3703E	3703E	3703	3753E	3753	0000
8 28 5 5W4	3248	2586	3511E	3511E	3511	3677	3583	3785

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LOCATION	KB	KFS	GLAD	CUTB	SRS	SS	JR	JSTH
15 28 5 5W4	3265	2589	3614E	3614E	3614E	3614	3629	3770
15 29 5 5W4	3192	2489	3428E	3428E	3428	3490	3506	3664
6 14 5 6W4	3005	2280	3122	3207E	3207	3271E	3271	3408
8 28 5 6W4	2929	2182	3058	3110E	3110	3178E	3178	3330
14 13 5 7W4	2865	2087	2872	3025E	3025	3085E	3085	3242
6 10 5 8W4	2829	1901	2822	2882E	2882	2900	2916	3100
11 7 5 9W4	3001	1983	2953	3000E	3000E	3000	3018	3125
11 12 5 9W4	2883	1922	2888	2910E	2910	2930	2956	3082
6 7 5 10W4	3008	1950	2920	3018E	3018E	3018E	3018	3048
11 14 5 10W4	3018	2012	2985	3017E	3017E	3017	3031	3154
6 30 5 12W4	3077	2001	2944	3002E	3002E	3002	3013	3085
16 21 5 13W4	3058	1978	2887	2925E	2925	2974	2981	3073
10 16 5 14W4	2988	1850	2782	2869E	2869E	2869	2884	2970
11 23 5 14W4	2977	1913	2838	2914E	2914	2928	2946	3032
3 17 5 15W4	3127	1941	2892	2982E	2982	2982	3000	3081
11 21 5 15W4	3102	1960	2878	2967E	2967E	2967	2985	3078
13 10 5 16W4	3194	2020	3034	3084E	3084E	3084	3100	3187
15 30 5 16W4	3123	2040	3058	3109E	3109E	3109E	3109	3182
4 24 5 17W4	3171	2120	3054	3125	3153E	3153E	3153	3199
6 30 5 17W4	3234	2237	3280	3305	3381E	3381E	3381	3442
2 36 5 17W4	3134	2028	3084	3120	3160E	3160E	3160	0000
6 5 5 18W4	3380	2248	3313	3340	3381E	3381E	3381	3470

15 29 5 19W4	3250	2379	3370	3454	3501E	3501E	3501	3610
6 15 6 1W4	3736	3391	4318E	4318E	4318E	4318	4350	4528
6 14 6 2W4	3627	3223	4139E	4139E	4139E	4139	4183	4344
5 28 6 4W4	3682	3121	4012E	4012E	4012	4082	4108	4232
11 17 6 5W4	3427	2762	3639	3695E	3695	3713	3747	3820
8 9 6 6W4	3085	2366	3230	3292E	3292	3331E	3331	3483
11 2 6 7W4	2878	2113	3110E	3110E	3110E	3110E	3110	3238
13 5 6 7W4	2951	2023	2955	2988E	2988	3000E	3000	3183
6 23 6 7W4	2976	2224	3199E	3199E	3199E	3199	3216	3358
6 31 6 8W4	2848	1980	3026	3084E	3084E	3084E	3084	3156
7 6 6 9W4	2934	2047	3034	3093E	3093E	3093E	3093	3165
6 6 6 10W4	3022	2046	3015	3100E	3100E	3100E	3100	3137
6 10 6 10W4	2856	2054	3022	3100E	3100E	3100E	3100	3153
6 13 6 11W4	3033	2071	3045	3116E	3115E	3116E	3115	3153
7 31 6 12W4	2884	1960	2820	2893E	2893	0000	0000	0000
10 5 6 13W4	3055	2027	2928	2970E	2970	2988	3018	3108
6 33 6 13W4	2987	2085	2954	3035E	3035E	3035E	3035	3100
4 32 6 14W4	3008	2099	3088	3103E	3103E	3103E	3103	3185
1 5 6 15W4	2860	1850	0000	2854E	2854E	2854	2868	2958
14 24 6 15W4	3066	2080	3081E	3081E	3081E	3081E	3081	3176
15 36 6 15W4	3020	2090	3080E	3080E	3080E	3080E	3080	3170
6 7 6 16W4	3157	2136	3173	3204	3240E	3240E	3240	3300
10 10 6 18W4	3088	2070	3080	3138	3178E	3178E	3178	3218

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LOCATION	KB	KFS	GLAD	CUTB	SRS	SS	JR	JSTH
11 24 6 18W4	3098	2152	3120	3206E	3206E	3206E	3206	3284
13 13 6 17W4	2958	1968	3017	3074	3095E	3095E	3095	3129
6 16 6 17W4	3060	2260	3305	3350	3387E	3387E	3387	3424
8 35 6 17W4	3127	2187	3233	3278	3306E	3306E	3306	3350
10 11 6 18W4	3206	2305	3356	3377	3460E	3460E	3460	3525
10 35 6 18W4	3110	2376	3414	3447	3526E	3526E	3526	3600
7 16 6 20W4	3132	2600	3670	3740	3771E	3771E	3771	3815
8 18 7 1W4	4428	3891	4928E	4928E	4928	4962E	4962	5115
6 23 7 3W4	4207	3758	4632E	4632E	4632	4704	4712	4873
12 32 7 4W4	3890	3151	4002E	4002E	4002	4057	4085	4241
7 6 7 5W4	3521	2865	3790E	3790E	3790	3842E	3842	3895
6 4 7 6W4	3353	2890	3629E	3629E	3629E	3629	3640	3778
6 29 7 7W4	2835	2140	3108	3176E	3176E	3176E	3176	3206
10 4 7 8W4	2768	2034	2993	3058E	3058E	3058E	3058	3118
10 22 7 9W4	2785	2024	0000	3074E	3074E	3074E	3074	3114
6 11 7 10W4	2807	2001	2944	3021E	3021E	3021E	3021	3085
5 33 7 10W4	2834	2038	2966	3032E	3032E	3032E	3032	3088
2 6 7 11W4	2860	1948	2885	2928E	2928E	2928E	2928	2991
11 7 7 12W4	2891	1992	2885	2936E	2936E	2936	2984	3050
8 15 7 12W4	2842	1943	2800	2872E	2872E	7872	2887	2980
9 23 7 12W4	2825	1856	2810	2894E	2894E	2894	2917	2982
10 10 7 13W4	2922	2058	2995	3027E	3027E	3027E	3027	3100
16 13 7 13W4	2855	1885	2810	2930E	2930E	2930E	2930	3030
2 16 7 13W4	2914	2050	2990	3020E	3020E	3020E	3020	3080
6 1 7 14W4	2925	2042	3032E	3032E	3032E	3032E	3032	3098
4 15 7 14W4	2811	1968	2980E	2980E	2980E	2980E	2980	3030
16 17 7 14W4	2886	1838	2855E	2855E	2855E	2855E	2855	2912
15 20 7 14W4	2897	2070	3058	3084E	3084E	3084E	3084	0000
3 27 7 14W4	2874	2088	3050	3060	3076E	3076E	3076	3150
4 28 7 14W4	2930	2100	3090	3100	3133E	3133E	3133	3172
1 30 7 14W4	2926	2098	3071	3092	3126E	3126E	3126	0000
11 10 7 15W4	3071	2180	3161E	3161E	3161E	3161E	3161	3238
11 14 7 15W4	2990	2123	3115E	3115E	3115E	3115E	3115	3188
10 24 7 15W4	2958	2120	3109E	3109E	3109E	3109E	3109	3186
4 30 7 15W4	2812	1944	2970	2980	3044E	3044E	3044	3080
4 36 7 15W4	2939	2115	3104	3128	3180E	3180E	3180	0000
10 2 7 16W4	3098	2201	3235	3255	3304E	3304E	3304	3320
6 4 7 16W4	3102	2210	3236	3318E	3318E	3318E	3318	3349
10 7 7 16W4	3100	2248	3210	3270	3302E	3302E	3302	3368
7 9 7 16W4	3096	2212	3185	3284E	3284E	3284E	3284	3332
10 13 7 16W4	3047	2156	3182	3200	3251E	3251E	3251	3262
10 15 7 16W4	3080	2206	3194	3270E	3270E	3270E	3270	3318
8 19 7 16W4	3053	2222	3228	3261	3300E	3300E	3300	3340
7 28 7 16W4	2894	2184	3177	3203	3232E	3232E	3232	3278
11 36 7 16W4	2989	2160	3150	3206	3218E	3218E	3218	3238

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LOCATION	KB	KPS	GLAD	CUTB	SRS	SS	JR	JSTH
10 2 7 17W4	3121	2217	3255	3270	3352E	3352E	3352	3374
9 16 7 17W4	3123	2356	3287	3325	3422E	3422E	3422	3459
7 19 7 17W4	3132	2439	3466	3515	3559E	3559E	3559	3608
14 35 7 17W4	3029	2224	3230	3274	3314E	3314E	3314	3356
11 2 7 18W4	3137	2427	3452	3486	3550E	3550E	3550	3615
14 2 8 2W4	4664	4332	5248E	5248E	5248	5281E	5281	5443
5 36 8 3W4	4040	3646	4478E	4478E	4478	4549	4585	4700
6 1 8 4W4	3732	3234	4051	4089E	4089	4175	4186	4337
10 21 8 5W4	3721	3181	4064E	4064E	4064	4108E	4108	4250
11 5 8 6W4	3201	2580	3522E	3522E	3522E	3522E	3522	3655
14 34 8 7W4	3030	2425	3390E	3390E	3390E	3390E	3390	3483
10 29 8 10W4	2784	2044	3012E	3012E	3012E	3012E	3012	3058
1 10 8 11W4	2785	1987	0000	2935E	2935E	2935E	2935	3010
8 22 8 12W4	2737	1986	2868	2918E	2918E	2918E	2918	3001
4 3 8 14W4	2901	2146	3123E	3123E	3123E	3123E	3123	3182
2 5 8 14W4	2904	2134	3110E	3110E	3110E	3110E	3110	3180
5 8 8 14W4	2930	2151	3144E	3144E	3144E	3144E	3144	3222
7 28 8 14W4	2852	2162	3161E	3161E	3161E	3161E	3161	3227
10 30 8 14W4	2866	2178	3172E	3172E	3172E	3172E	3172	3230
15 34 8 14W4	2795	2088	3078E	3078E	3078E	3078E	3078	3150
10 6 8 15W4	2962	2157	3182	3205	3229E	3229E	3229	3242
8 7 8 15W4	2928	2146	3155	3174	3213E	3213E	3213	3218
14 9 8 15W4	2886	2134	3119	3140	3200E	3200E	3200	3212
8 19 8 15W4	2853	2136	3124	3165	3176E	3176E	3176	3187
6 21 8 15W4	2847	2133	3175E	3175E	3175E	3175E	3175	3222
11 5 8 16W4	2970	2174	3145	3182	3206E	3206E	3206	3278
12 20 8 16W4	2881	2148	3136	3166	3203E	3203E	3203	3249
2 21 8 16W4	2805	2180	3185	3186	3192E	3192E	3192	3245
10 23 8 16W4	2875	2155	3123	3176	3190E	3190E	3190	3213
11 29 8 16W4	2842	2136	3114	3156	3200E	3200E	3200	3233
8 32 8 16W4	2814	2111	3090	3128	3164E	3164E	3164	3200
15 32 8 16W4	3181	2106	3053	3103	3164E	3164E	3164	0000
13 33 8 16W4	2791	2111	3086	3125	3151E	3151E	3151	0000
2 36 8 16W4	2784	2084	3088	3160	3172E	3172E	3172E	3172
11 1 8 17W4	2895	2200	3220E	3220	3263E	3263E	3263E	3263
7 33 8 17W4	2869	2231	3217	3240	3304E	3304E	3304	3337
11 18 8 19W4	3029	2605	3651	3690	3725E	3725E	3725	3814
4 5 8 20W4	3039	2682	3760	3803	3821E	3821E	3821	3854
10 11 9 1W4	3492	3240	4098E	4098E	4098	4131	4143	4289
7 15 9 2W4	3876	3636	4361E	4361E	4361	4440E	4440	4594
10 15 9 3W4	3779	3411	4240E	4240E	4240	4302E	4302	4445
11 29 9 4W4	3405	2834	3776E	3776E	3776	3814	3827	3834
11 20 9 7W4	2804	2216	3183E	3183E	3183E	3183E	3183	3232
11 24 9 8W4	2545	1927	2867	2916E	2916E	2916E	2916	2941
13 5 9 9W4	2780	2100	3105E	3105E	3105E	3105E	3105	3128

POOR COPY
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LOCATION	KB	KFS	GLAD	CUTB	SRS	SS	JR	JSTH
5 7 9 10W4	2786	2086	3005	3074E	3074E	3074E	3074	3102
1 36 9 13W4	2878	2037	2941E	2941E	2941E	2941E	2941	2976
7 13 9 14W4	2742	2079	3070E	3070E	3070E	3070E	3070	3148
10 4 9 15W4	2812	2150	3138	3173	3220	3220E	3220E	3220
4 4 9 16W4	2782	2082	3050	3100	3124E	3124E	3124	3165
1 5 9 16W4	2784	2098	3054	3112	3150E	3150E	3150	0000
16 6 9 16W4	2747	2075	0000	3103	3158E	3158E	3158	3179
5 14 9 16W4	2712	2083	0000	3145	EEEE	EEEE	EEEE	0000
4 19 9 16W4	2753	2130	3132	3184	3212E	3212E	3212	3241
4 32 9 16W4	[illegible]	2124	3080	3145	EEEE	EEEE	0000	0000
8 26 9 17W4	2733	2188	3187	3220	3270E	3270E	3270	3282
14 31 9 17W4	2721	2228	3228	3283	3308E	3308E	3308	3328
7 10 9 18W4	2638	2225	3244	3283	EEEE	EEEE	0000	0000
11 27 9 18W4	2733	2277	3287	3303	3382E	3382E	3382	3390
10 30 9 19W4	2820	2630	3583	3628	3645E	3645E	3645	3712
4 8 9 20W4	2824	2675	3780	3819	3838E	3838E	3838	3917
10 11 10 2W4	3230	2890	3781E	3781E	3781	3648	3871	3984
7 14 10 4W4	3242	[illegible]	3710E	3710E	3710	3730E	3730	3844
10 27 10 5W4	2864	2390	3153E	3153E	3153	3222E	3222	3341
10 36 10 5W4	2902	2448	3227E	3227E	3227	3272E	3272	3386
4 9 10 6W4	2835	2405	3319	3368E	3368E	3368E	3368	3388
10 4 10 7W4	2645	2084	3055	3055E	3055E	3055E	3055	3107
4 15 10 9W4	2788	2173	3081	3120E	3120E	3120E	3120	3142
15 3 10 10W4	2851	2217	3077E	3077E	3077E	3077E	3077	3107
3 5 10 10W4	2849	2222	3122E	3122E	3122E	3122E	3122	3143
5 15 10 11W4	2682	2045	2976E	2976E	2976E	2976E	2976E	2976
13 22 10 12W4	2683	1991	2950E	2950E	2950E	2950E	2950E	2950
10 34 10 12W4	2617	2030	2976E	2976E	2976E	2976E	2976E	2976
5 17 10 13W4	2623	2038	2963E	2963E	2963E	2963E	2963	2984
8 25 10 13W4	2622	2040	2973E	2973E	2973E	2973E	2973	2998
11 5 10 14W4	2681	2088	3080E	3080E	3080E	3080E	3080	3114
8 28 10 15W4	2613	2080	3084E	3084E	3084E	3084E	3084	3110
6 26 10 16W4	2693	2098	3131E	3131E	3131E	3131E	3131	3183
4 27 10 16W4	2620	2178	3183	3227	3249E	3249E	3249	3267
5 13 10 17W4	2653	2178	3179	3202	3288E	3288E	3288E	3288
10 7 10 18W4	2785	2392	3403	3454	3490E	3490E	3490	3520
10 14 10 19W4	2800	2435	3479	3546	3580E	3580E	3580	3597
10 32 10 19W4	2818	2549	3580	3632	3650E	3650E	3650	3700
10 28 10 20W4	2854	2682	3698	3737	3782E	3782E	3782	3854
12 36 11 1W4	2478	2249	3039E	3039E	3039	3090	3101	3238
12 11 11 4W4	2630	2431	EEEE	EEEE	0000	0000	3280	3370
7 2 11 6W4	2776	2314	3086E	3086E	3086	3114E	3114	3222
11 22 11 6W4	2738	2210	3112	3149E	3149E	3149E	3149	3158
10 12 11 10W4	2764	2210	3147	3183E	3183E	3183E	3183	3200
8 31 11 12W4	2475	1984	2904	2951E	2951E	2951E	2951E	2951

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LOCATION	KB	KPS	GLAD	CUTB	SRS	SS	JR	JSTH
12 13 11 13W4	2563	2035	3005	3088E	3088E	3088E	3088E	3088
14 29 11 13W4	2465	1969	2905	2988E	2988E	2988E	2988	2980
6 27 11 14W4	2556	2098	0000	0000	EEEE	EEEE	EEEE	0000
5 36 11 14W4	2504	2015	2945	2992E	2992E	2992E	2992	2998
6 19 11 15W4	2573	2157	0000	0000	EEEE	EEEE	EEEE	0000
8 32 11 15W4	2575	2172	0000	3155E	3155E	3155E	3155E	3155
7 15 11 16W4	2584	[illegible]	3201	3251E	3251E	3251E	3251E	3251
8 14 11 17W4	2632	2249	3253	3288	3368E	3368E	3368E	3368
6 10 11 18W4	2615	2469	3480	3555	3593E	3593E	3593	3600
10 30 11 18W4	2807	2578	3593	3646	3654E	3654E	3654	3665
11 10 11 19W4	2783	2485	3485	3525	3563E	3563E	3563	3596
10 22 11 20W4	2862	2774	3768	3808	3828E	3828E	3828	3865
7 28 12 2W4	2867	2394	3209E	3209E	3209	3230E	3230	3330
8 29 12 3W4	2573	2218	2958E	2958E	2958	3029E	3029	3152
11 8 12 9W4	2725	2215	3182	3185E	3185E	3185E	3185E	3185
10 18 12 10W4	2515	2007	2865	2976E	2976E	2976E	2976E	2976
8 5 12 12W4	2463	1856	2936	3017E	3017E	3017E	3017E	3017
12 14 12 12W4	2488	1998	0000	EEEE	EEEE	EEEE	EEEE	0000
8 5 12 13W4	2452	1980	2940E	2940E	2940E	2940E	2940E	2940
6 11 12 13W4	2444	1878	2923	2966E	2966E	2966E	2966E	2966
7 30 12 13W4	2539	2106	3024E	3024E	3024E	3024E	3024E	3024
13 11 12 14W4	2666	2107	2993E	2993E	2993E	2993E	2993	3016
7 14 12 14W4	2561	2095	3010E	3010E	3010E	3010E	3010E	3010
16 33 12 14W4	2605	2227	3213E	3213E	3213E	3213E	3213E	3213
10 14 12 15W4	2557	2258	0000	3169	3182E	3182E	3182E	3182
13 24 12 15W4	2623	2230	0000	3055	3107E	3107E	3107E	3107
6 28 12 16W4	2583	2263	3208	3272	3278E	3278E	3278E	3278
12 21 12 18W4	2728	2535	3828	3820	EEEE	EEEE	0000	0000
3 20 12 19W4	2785	2702	3688	3741	3781E	3781E	3781	3782
7 28 12 20W4	2788	2812	3682	3802	3850E	3850E	3850	3870
11 31 13 1W4	2414	2167	2990E	2990E	2990E	2990E	2990	3083
10 11 13 4W4	2486	2106	2910E	2910E	2910	2950E	2950	3035
16 30 13 7W4	2570	2134	2932	2978E	2978E	2978E	2978E	2978
16 28 13 8W4	2575	2180	3080	3180E	3180E	3180E	3180E	3180
3 27 13 9W4	2630	2120	3007	3120E	3120E	3120E	3120E	3120
10 21 13 11W4	2464	2042	2920E	2920E	2920E	2920E	2920E	2920
10 4 13 13W4	2592	2195	3138	3228E	3228E	3228E	3228E	3228
4 9 13 13W4	2616	2189	3115E	3115E	3115E	3115E	3115E	3115
4 20 13 13W4	2595	2205	3125	3181E	3181E	3181E	3181E	3181
15 28 13 14W4	2580	2200	3078	3150E	3150E	3150E	3150E	3150
6 21 13 16W4	2575	2262	3251	3398E	3398E	3398E	3398E	3398
3 34 13 17W4	2635	2402	3290	3365E	3365E	3365E	3365	3383
7 19 13 18W4	2754	2708	3684	3798	3839E	3839E	3839E	3839
7 15 13 19W4	2716	2664	3683	0000	EEEE	EEEE	0000	0000
8 10 14 7W4	2593	2190	3000	3052E	3052E	3052E	3052E	3052

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LOCATION	KB	KFS	GLAD	CUTB	SRS	SS	JR	JSTH
6 22 14 8W4	2461	2110	2883	3112E	3112E	3112E	3112E	3112
3 10 14 9W4	2541	2173	3050	3153E	3153E	3153E	3153E	3153
7 28 14 10W4	2461	2086	2968	3102E	3102E	3102E	3102E	3102
7 14 14 11W4	2521	2147	2898	3088E	3088E	3088E	3088E	3088
4 34 14 13W4	2460	2200	3143	3252E	3252E	3252E	3252E	3252
10 11 14 14W4	2487	2144	3080	3144E	3144E	3144E	3144E	3144
4 36 14 14W4	2460	2204	3158	EEEE	EEEE	EEEE	0000	0000
7 15 14 15W4	2495	2226	3102	3187E	3187E	3187E	3187E	3187
7 14 14 16W4	2504	2246	3132	3218E	3218E	3218E	3218E	3218
11 17 14 18W4	2678	2888	3850	3768E	3768E	3768E	3768E	3768
11 16 14 19W4	2728	2638	3775	3910E	3910E	3910E	3910E	3910
10 24 14 19W4	2878	2738	3756	EEEE	EEEE	EEEE	0000	0000
2 22 15 1W4	2661	2465	3350E	3350E	3350E	3350E	3350	3408
10 30 15 2W4	2624	2350	3117	3148E	3148E	3148E	3148	3188
3 17 15 3W4	2618	2204	3058	3105E	3105E	3105E	3105	3140
11 5 15 6W4	2500	2182	0000	3170E	3170E	3170E	3170E	3170
12 10 15 10W4	2471	2100	3015	3118E	3118E	3118E	3118E	3118
16 3 15 11W4	2442	2076	2880	3025E	3025E	3025E	3025E	3025
7 25 16 3W4	2708	2455	0000	3227E	3227E	3227E	3227E	3227
11 20 16 4W4	2460	2184	0000	EEEE	EEEE	EEEE	0000	2947

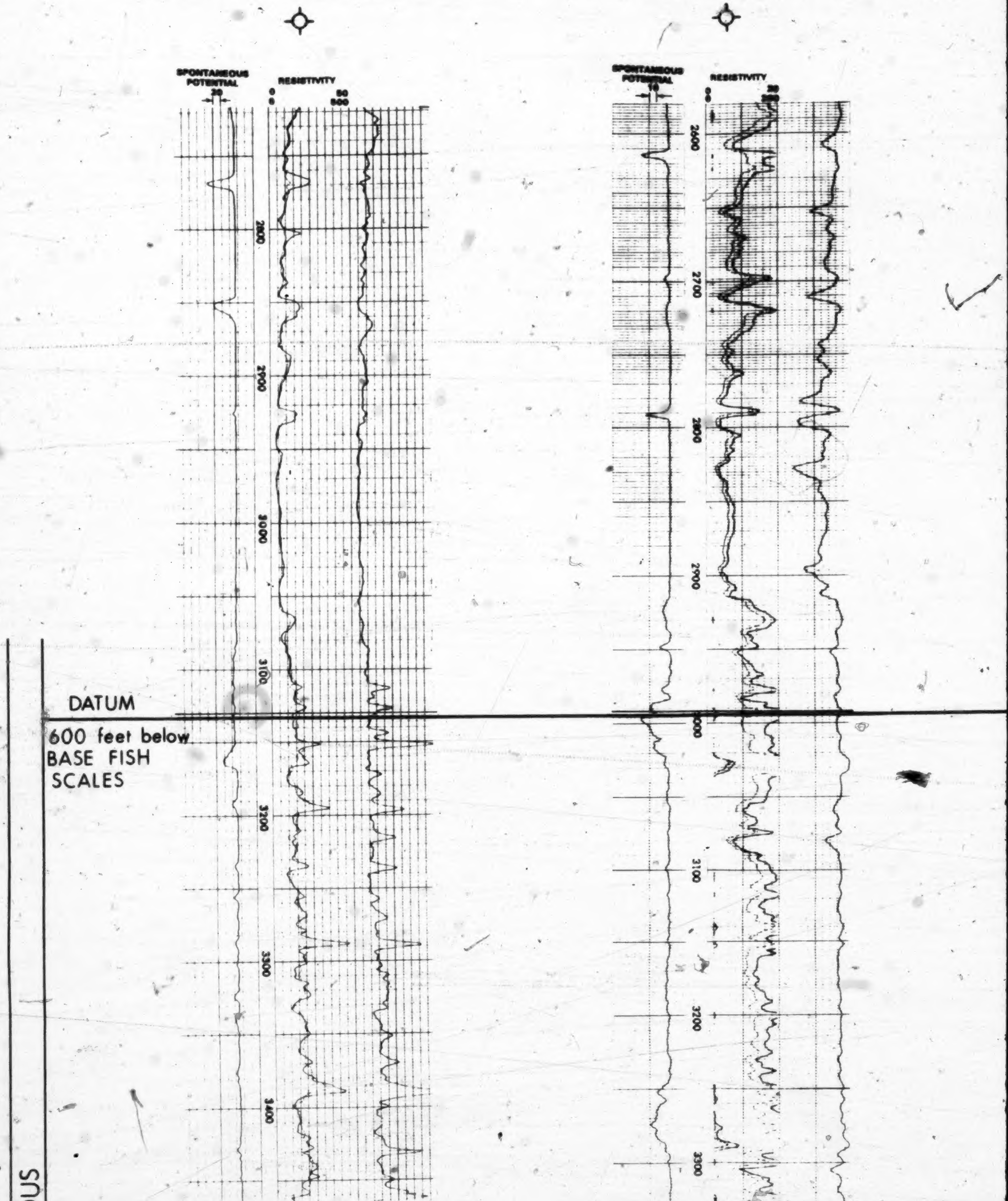
W1

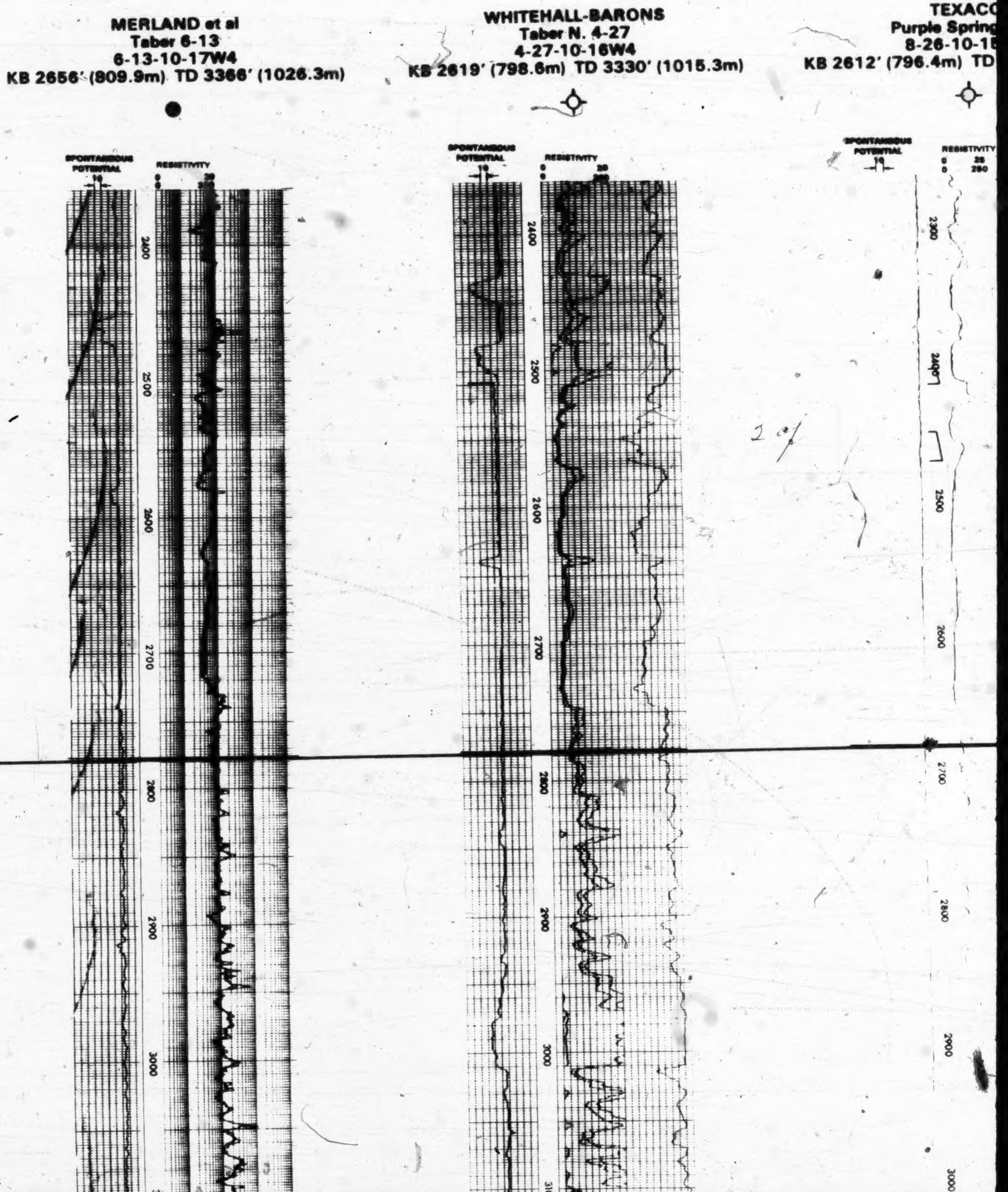
1 of

BOW VALLEY et al
Tempest 10-30
10-30-9-19W4
KB 2920' (860.1m) TD 3730' (1137.2m)

B.A.
Turin 10-7
10-7-10-18W4
KB 2784' (848.9m) TD 3619' (1103.4m)

KB 2



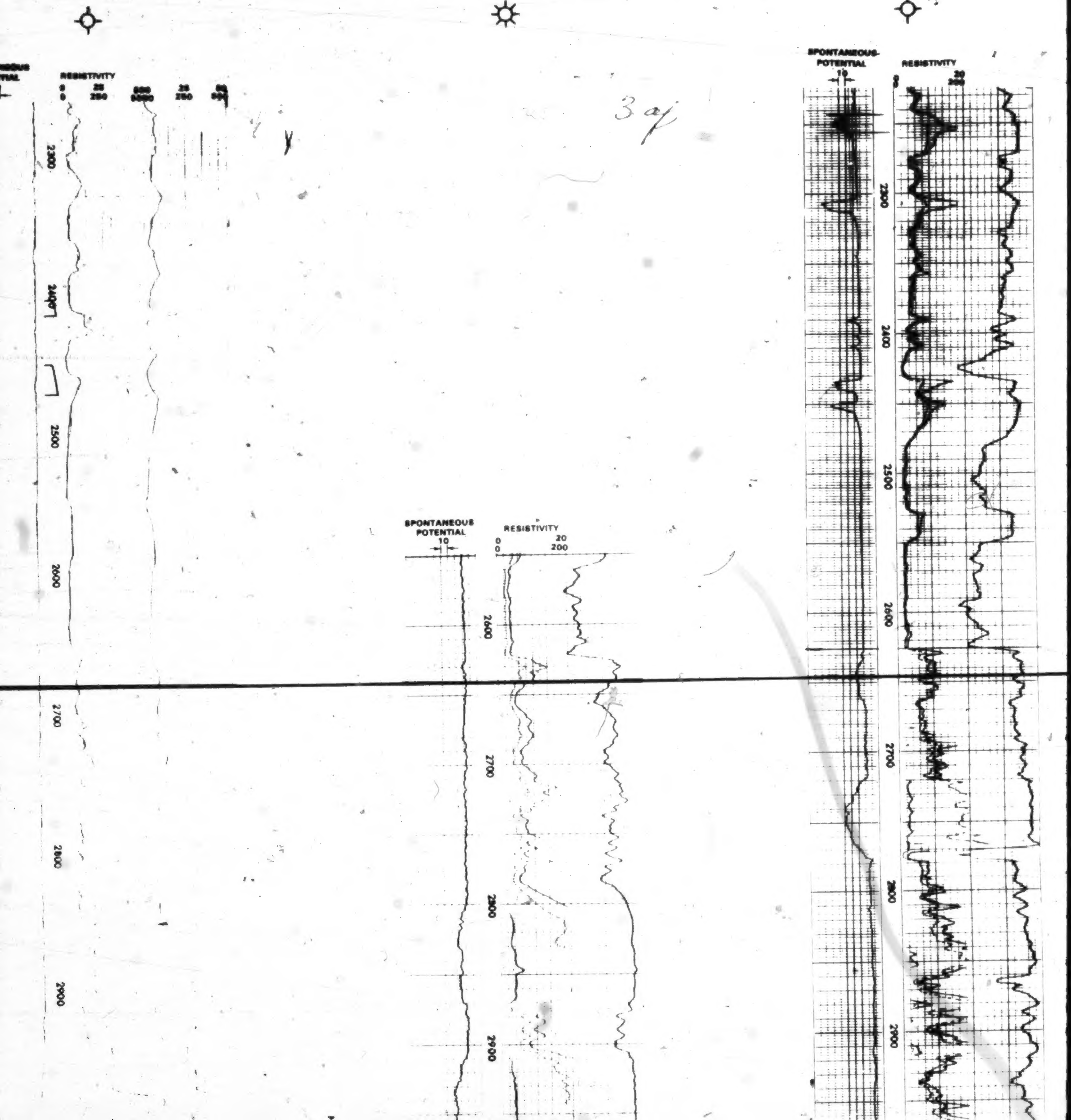
MERLAND et al
Taber 6-13
6-13-10-17W4
KB 2656' (809.9m) TD 3366' (1026.3m)
SPONTANEOUS POTENTIAL
10
RESISTIVITY
0 20
0 200
2400
2500
2600
2700
2800
2900
3000
WHITEHALL-BARONS
Taber N. 4-27
4-27-10-16W4
KB 2619' (798.6m) TD 3330' (1015.3m)
SPONTANEOUS POTENTIAL
10
RESISTIVITY
0 20
0 200
2400
2500
2600
2700
2800
2900
3000
TEXACO
Purple Spring
8-26-10-1
KB 2612' (796.4m) TD
SPONTANEOUS POTENTIAL
10
RESISTIVITY
0 25
0 250
2300
2400
2500
2600
2700
2800
2900
3000
2 of

TEXACO
Purple Springs A-1
8-26-10-15W4
(796.4m) TD 3174′ (967.7m)

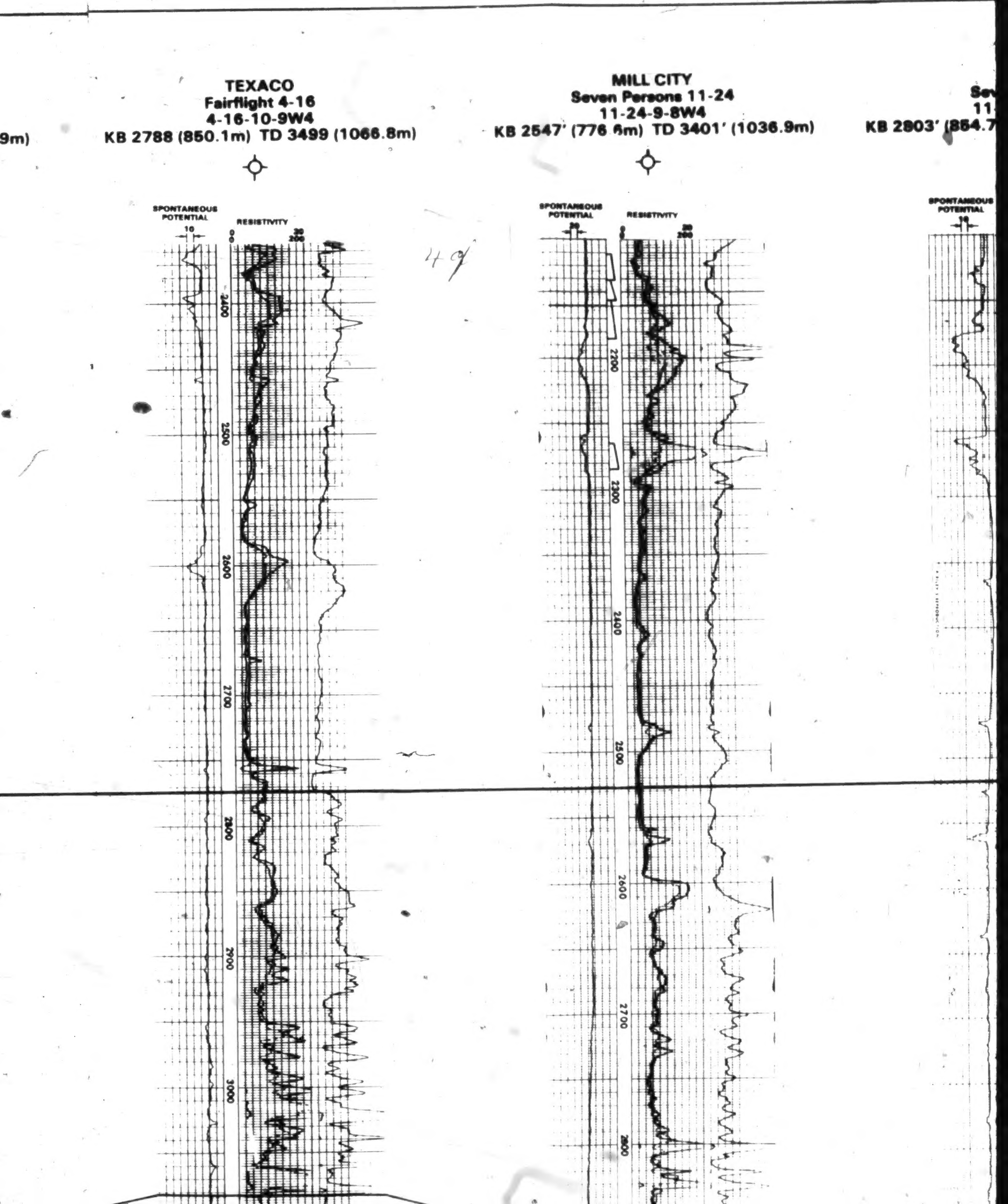
GPD
Grand Forks 6-25
6-25-10-13W4
KB 2661′ (811.4m) TD 3419′ (1011.9m)

UNO TEX
Bow Island 6-15
6-15-10-11W4
KB 2861′ (817.5m) TD 3076′ (937.9m

3 aj



49

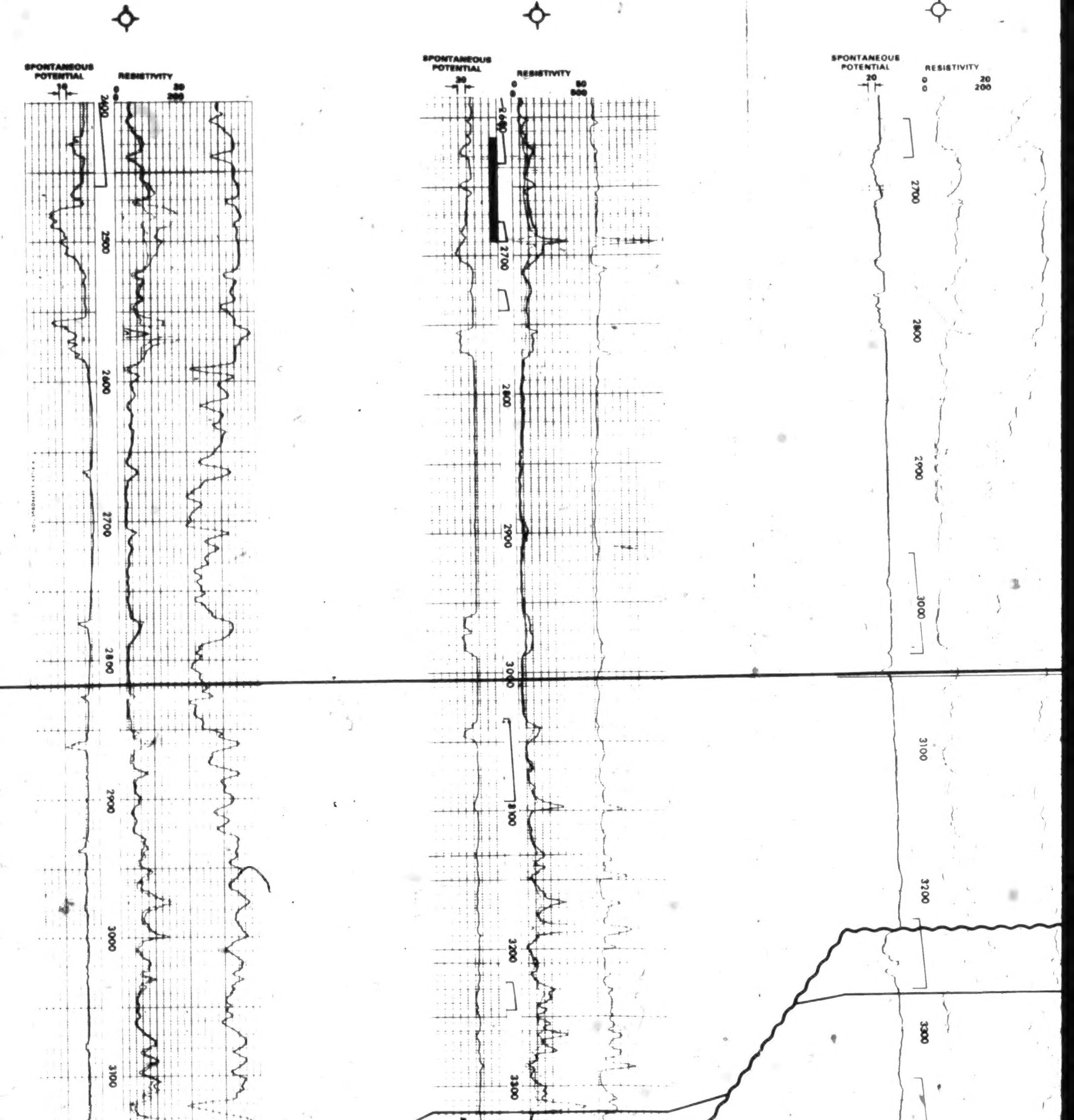

9m)
TEXACO
Fairflight 4-16
4-16-10-9W4
KB 2788 (850.1m) TD 3499 (1066.8m)
SPONTANEOUS POTENTIAL
10
RESISTIVITY
0
20
200
2400
2500
2600
2700
2800
2900
3000
MILL CITY
Seven Persons 11-24
11-24-9-8W4
KB 2547' (776.6m) TD 3401' (1036.9m)
SPONTANEOUS POTENTIAL
20
RESISTIVITY
0
20
200
2200
2300
2400
2500
2600
2700
2800
Sev
11
KB 2803' (854.7
SPONTANEOUS POTENTIAL
10

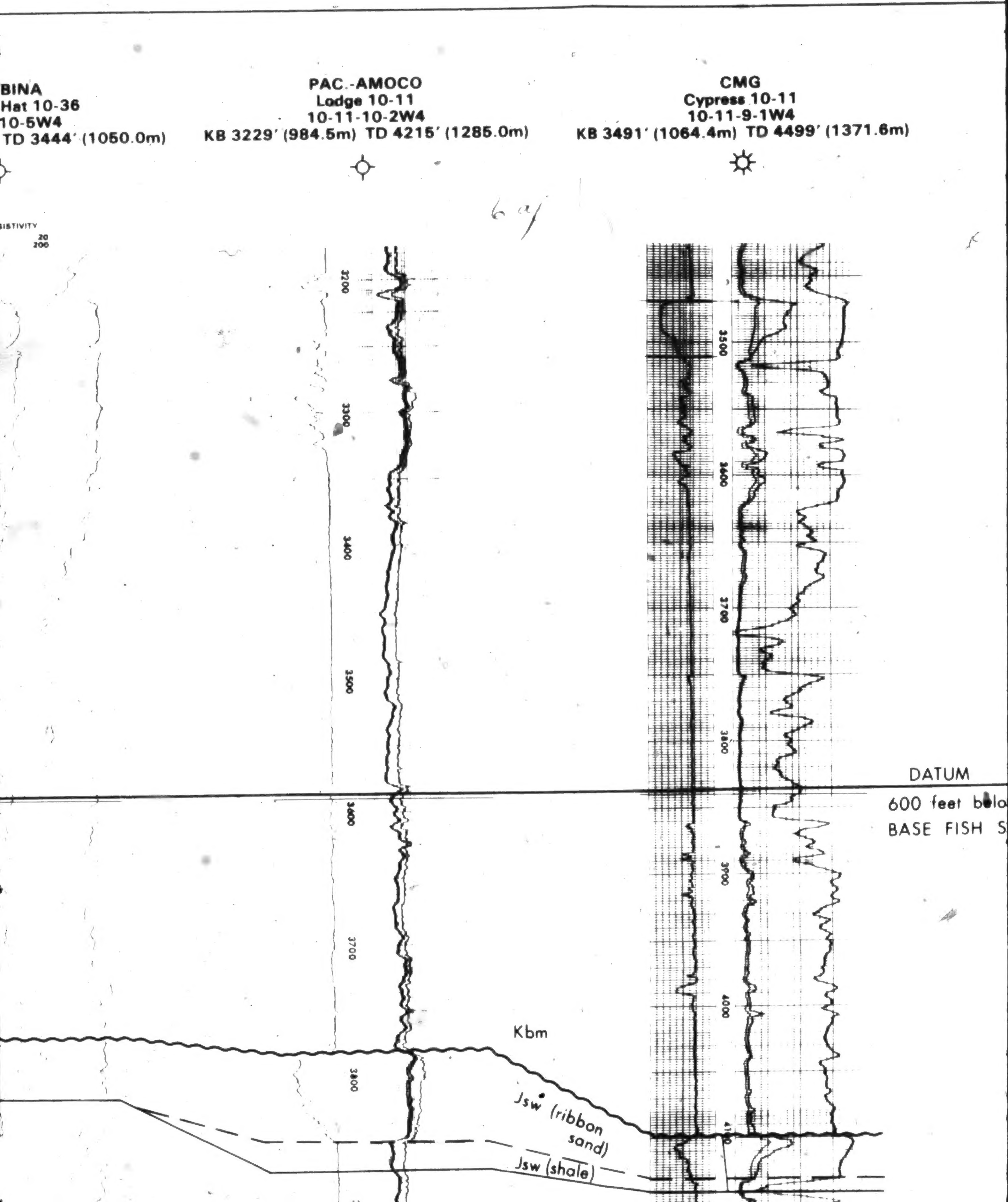
5 af

CMG
Seven Persons
11-20-9-7W4
803' (854.7m) TD 3338' (1017.7m)

SCHERCK-RICHTER
Roseberg No. 1
4-9-10-6W4
KB 2935' (894.9m) TD 3460' (1054.9m)

PEMBINA
Medicine Hat 10-36
10-36-10-5W4
KB 2901' (884.5m) TD 3444' (105

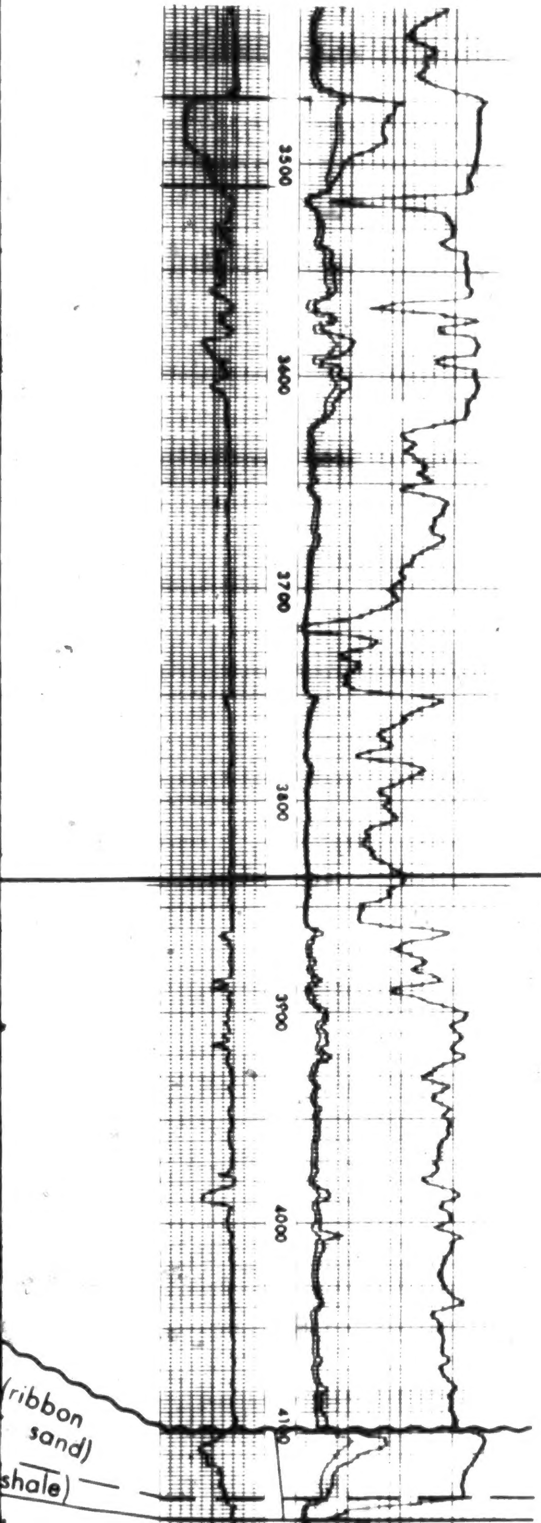



BINA
Hat 10-36
10-5W4
TD 3444' (1050.0m)
PAC.-AMOCO
Lodge 10-11
10-11-10-2W4
KB 3229' (984.5m) TD 4215' (1285.0m)
CMG
Cypress 10-11
10-11-9-1W4
KB 3491' (1064.4m) TD 4499' (1371.6m)
SISTIVITY
20
200
3200
3300
3400
3500
3600
3700
3800
3500
3600
3700
3800
3900
4000
4100
DATUM
600 feet belo
BASE FISH S
Kbm
Jsw (ribbon sand)
Jsw (shale)

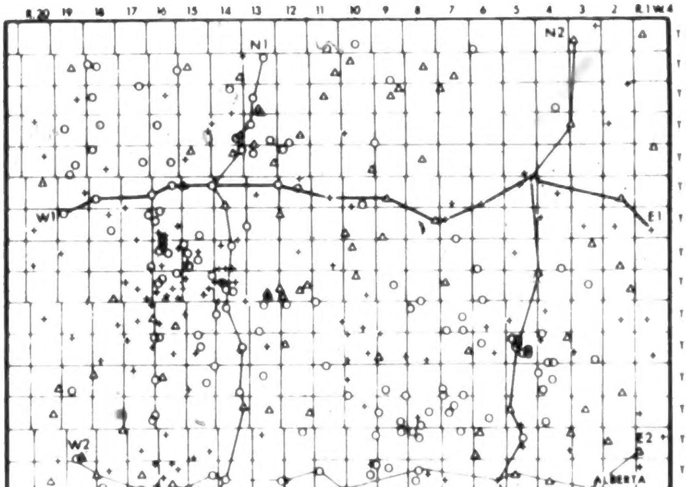
E1

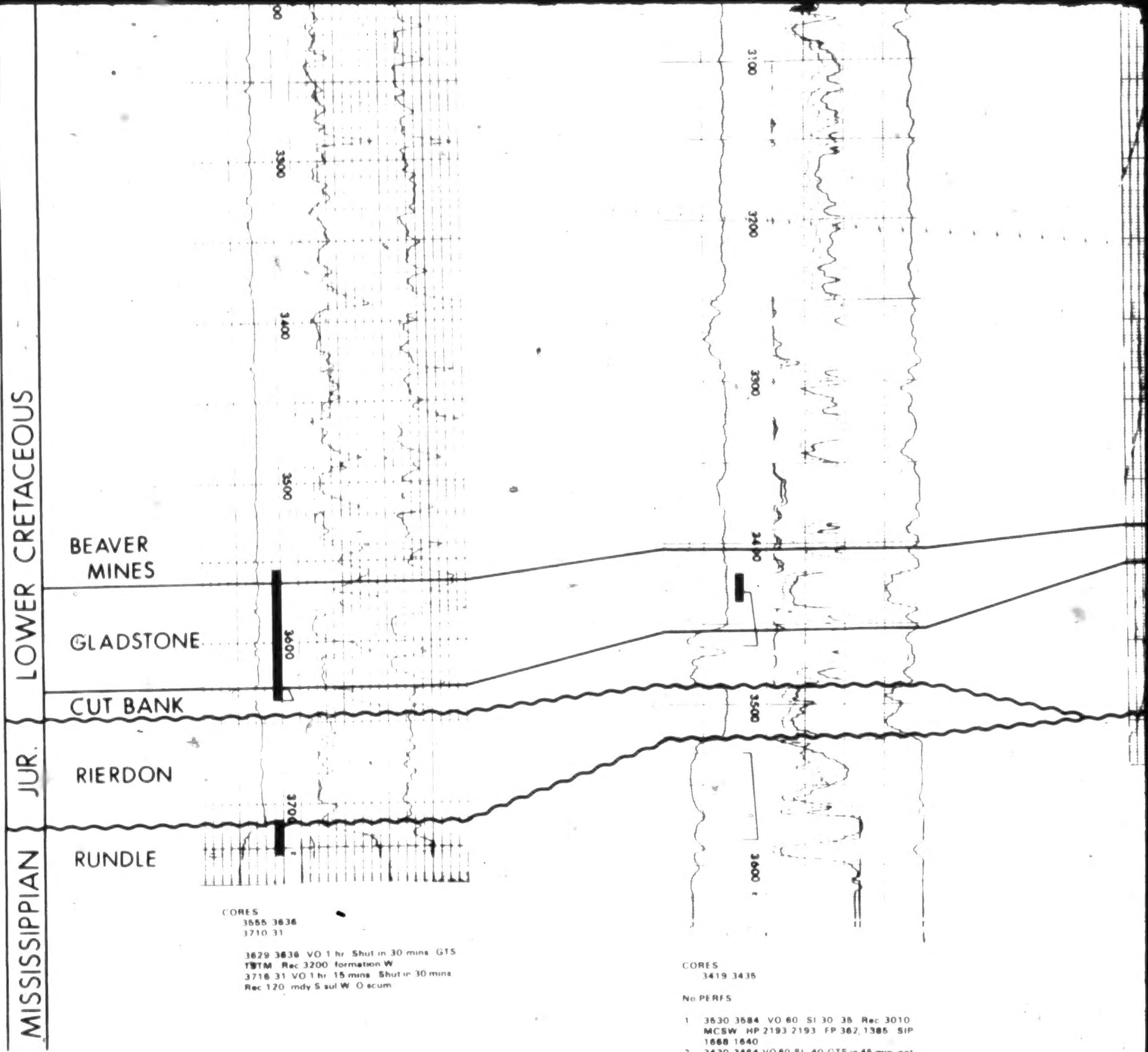
CMG
Cypress 10-11
10-11-9-1W4
KB 3491′ (1064.4m) TD 4499′ (1371.6m)

☼



DATUM
600 feet below
BASE FISH SCALES


R.20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
R.1W4
T15
T14
T13
T12
T11
T10
T9
T8
T7
T6
T5
T4
T3
T2
T1
N1
N2
W1
E1
W2
E2
ALBERTA


LOWER CRETACEOUS
BEAVER MINES
GLADSTONE
CUT BANK
JUR.
RIERDON
MISSISSIPPIAN
RUNDLE
3300
3400
3500
3600
3700
3100
3200
3300
3400
3500
3600

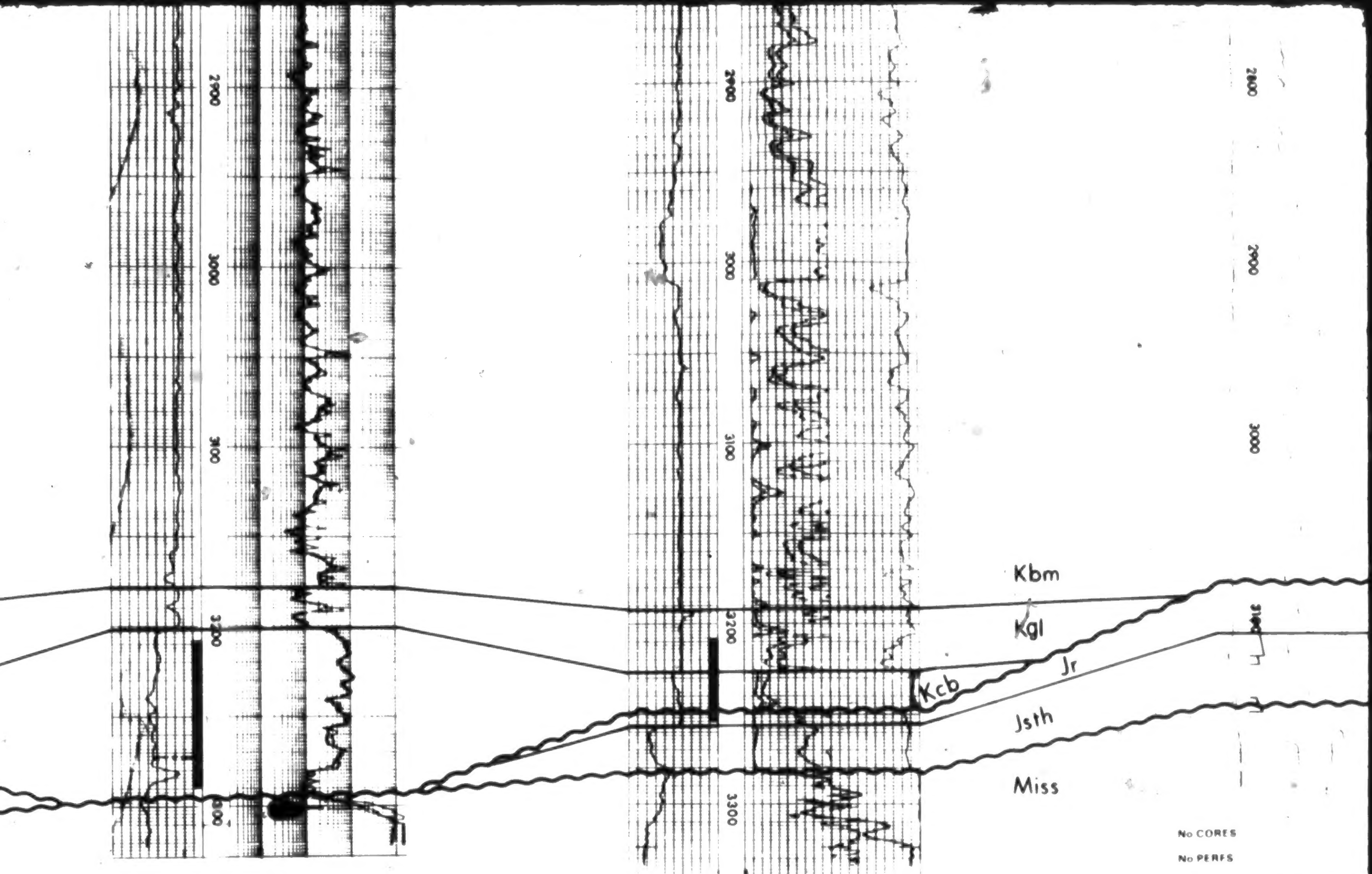
CORES
3555 3636
3710 31

3629 3636 VO 1 hr Shut in 30 mins GTS
TSTM Rec 3200 formation W
3716 31 VO 1 hr 15 mins Shut in 30 mins
Rec 120 mdy S sul W O scum

CORES
3419 3436

No PERFS

1 3630 3584 VO 60 SI 30 35 Rec 3010
MCSW HP 2193 2193 FP 382, 1385 SIP
1668 1640
2 3430 3464 VO 60 SI 40 GTS in 45 min not
measured Rec 3180 GC br SW HP 2158
2158 FP 725 1450 SIP 1518


2900
3000
3100
3200
3300
2800
2900
3000
3100
Kbm
Kgl
Jr
Kcb
Jsth
Miss

CORES
3208 68 Rec 60
3268 89 Rec 21

PERFS
3206 18 4 ft No treatment

No DST s

CORES
3209 3254 (46)

No PERFS

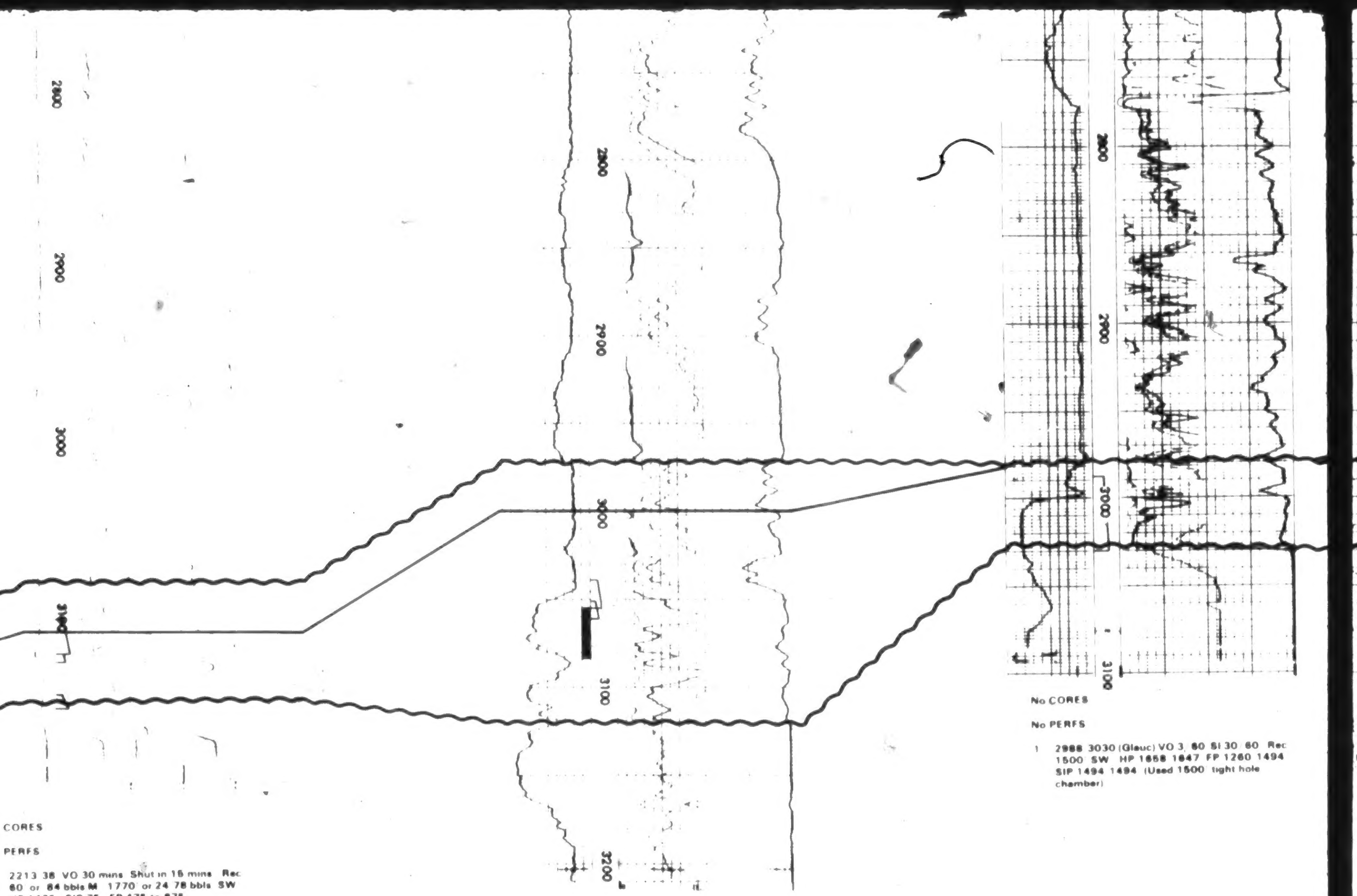
No DST s

No CORES

No PERFS

1 2213 38 VO 30 mins Shut in
60 or 84 bbls M 1770 or 24
HP 1425 SIP 75 FP 475 to
2 2406 16 VO 30 mins Shut in
VSAB dying in 10 mins Rec 3
M and 2130 or 29 82 bbls slty
FP 500 1000 SIP 1100
3 2451 71 VO 15 mins GIP G
84 bbls M 1380 or 18 90
1560 FP 300 700 SIP 925
4 3101 3121 VO 1½ hr GIP W
throughout test Rec 65 or
OCM HP 1950 FP 0
5 3121 26 VO 1½ hr Shut in
WAB 110 or 1 54 bbls sl
5 17 bbls sul SW HP 1950
200
6 3144 52 VO 30 mins Rec 20
M

9 of



CORES

PERFS

2213 38 VO 30 mins Shut in 15 mins Rec 60 or 84 bbls M 1770 or 24 78 bbls SW HP 1425 SIP 75 FP 475 to 875
2405 15 VO 30 mins Shut in 15 mins GIP VSAB dying in 10 mins Rec 30 or 42 bbls M and 2130 or 29 82 bbls slty W HP 1500 FP 500 1000 SIP 1100
2451 71 VO 15 mins GIP GAB Rec 60 or 84 bbls M 1350 or 18 90 bbls SW HP 1550 FP 300 700 SIP 925
3101 3121 VO 1½ hr GIP WAB continuing throughout test Rec 65 or 91 bbls hvy OCM HP 1950 FP 0
3121 28 VO 1½ hr Shut in 15 mins GIP WAB 110 or 1.54 bbls sli OCM 369 or 5 17 bbls sul SW HP 1950 SIP 1525 FP 200
3144 52 VO 30 mins Rec 200 or 2 80 bbls M

CORES
3055 84 Rec 29 Sidewall 2169 71 2 ft Rec 100%

PERFS
2184 5 87 5 2 ft Flw d G @ 550 Mcf d 3 8 ch

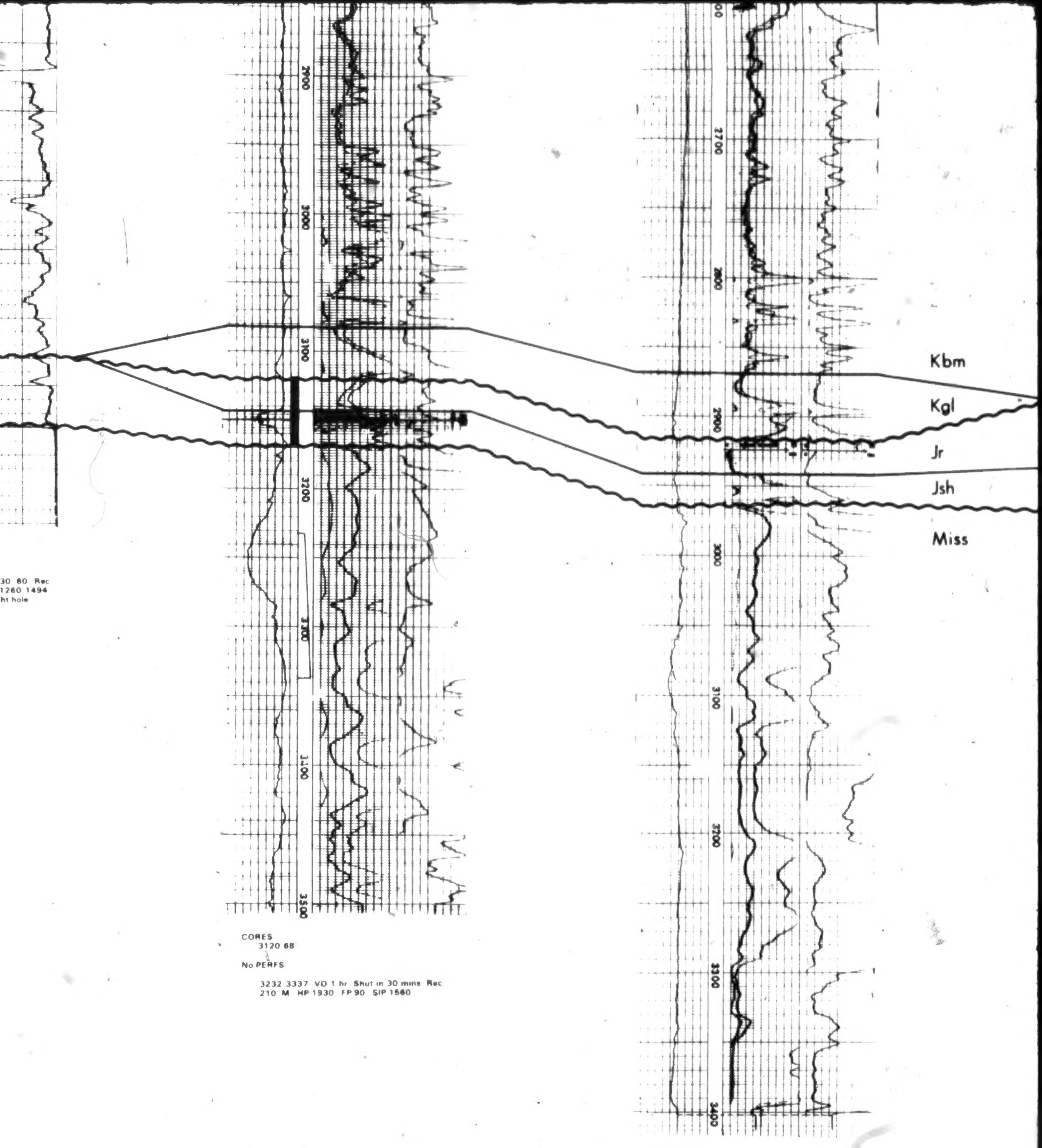
1 3039 55 (Glauc) VO 10 60 SI 60 90 Rec 200 clean O 1120 O & GCM HP 1663 1641 FP 219 552 SIP 1497 1497
2 3051 62 (Glauc) VO 10 180 SI 60 270 GTS 80 min TSTM WTS 118 min sli O flk d Rec 3055 sli O flk d W HP 1682 1682 FP 356 1347 SIP 1601 1601

No CORES

No PERFS

1 2988 3030 (Glauc) VO 3 60 SI 30 60 Rec 1500 SW HP 1658 1647 FP 1260 1494 SIP 1494 1494 (Used 1500 tight hole chamber)

10.of



30 60 Rec
1260 1494
ht hole

CORES
3120 68'

No PERFS

3232 3337 VO 1 hr Shut in 30 mins Rec 210' M HP 1930 FP 90 SIP 1560

No CORES

No PERFS

3 2060-2111 VO 1 hr. GTS in 15 mins TSTM. Rec 1810' or 25.34 bbls gsy mdy fr W. HP 1160 FP 830 SIP 830
4 2121-2141 VO 1 hr. GTS @ 276 MCFPD decr to 240 MCFPD. Rec 145' or 2.03 bbls M. HP 1180 FP 0 15 mins. SIP 826
5 2141-2156 VO 30 mins. GTS TSTM. Rec 10' or 0.14 bbls M.
6 2156-2186 VO 30 mins Rec 60' or 0.84 bbls M.
7 2266-2285 VO 35 mins. Rec 1623' or 22.71 bbls. gsy fr W.

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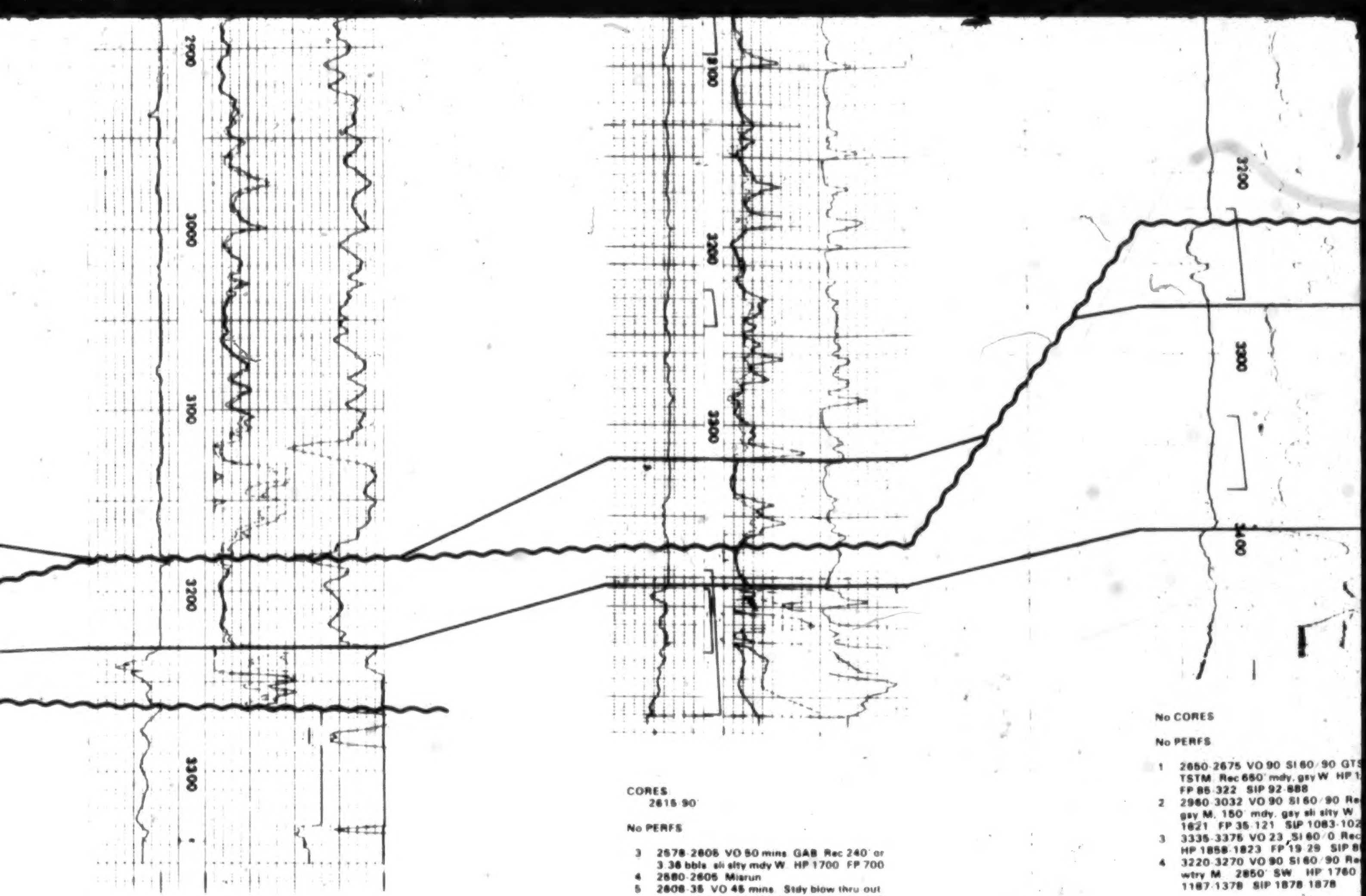


No CORES

No PERFS

5 2410 50 Misrun
6 2392 2460 (Bow ls) VO 15 60 SI 60 60 GTS in 4 min on PF max 60 Mcf Rec 30' M. 470' W HP 1273 1273 FP 90 156 SIP 845 813

CORES
2616 90'

No PERFS

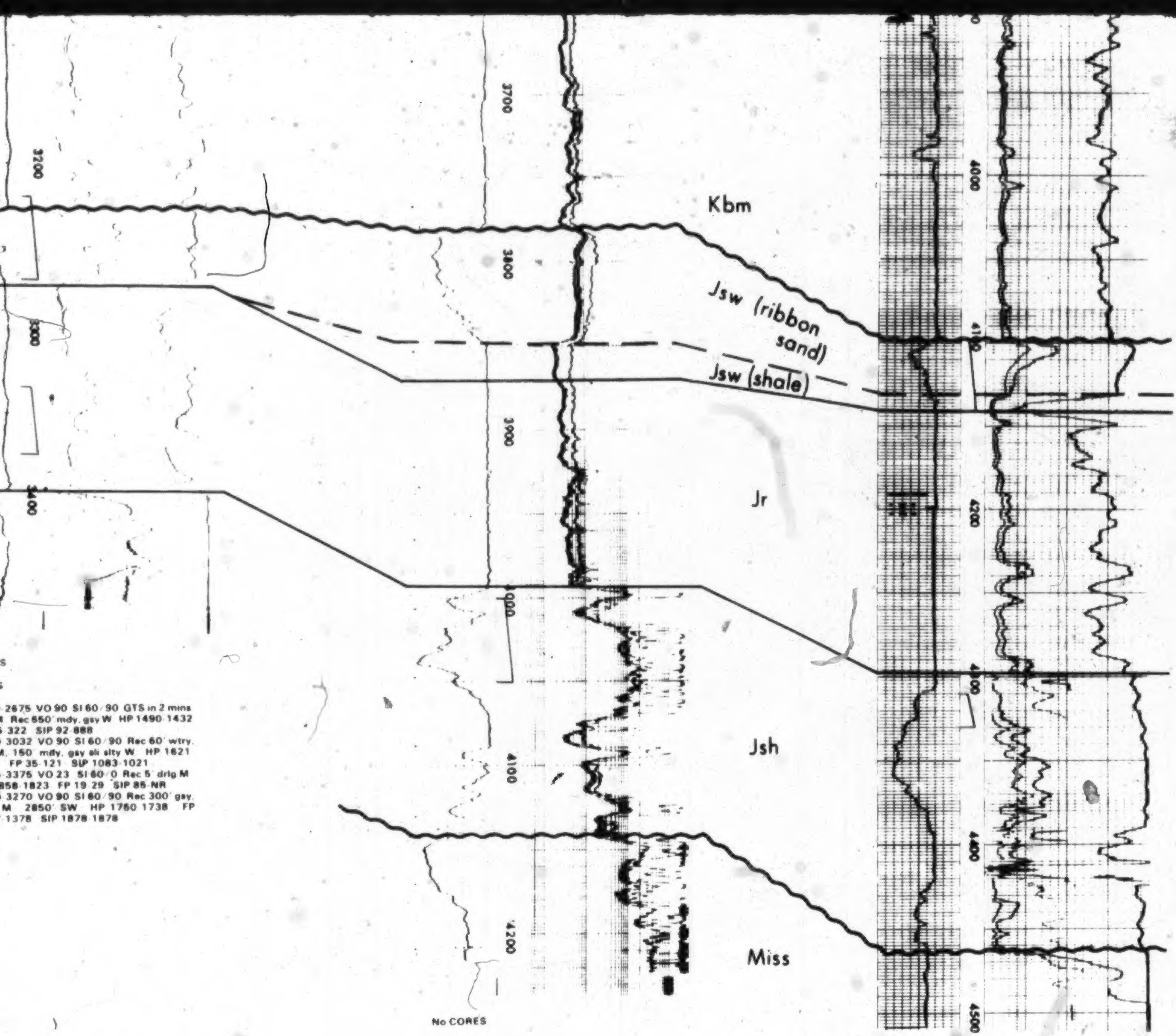
3 2578-2608 VO 50 mins GAB Rec 240' or 3 36 bbls sli slty mdy W HP 1700 FP 700
4 2580-2605 Misrun
5 2608-35 VO 45 mins Stdy blow thru out Rec 1030' or 14 42 bbls mdy slty W HP 1750 FP 400
6 2675-90 VO 45 mins Shut in 15 mins GAB thru-out Rec 1890' or 26 46 bbls sli slty W HP 1750 FP 600 SIP 910
7 2725-40 VO 30 mins FIP Died in 10 mins HP 1650 Rec 4' M
8 3033-93 VO 30 mins IP Rec 20' or 28 bbls M HP 1750
9 3225-45 VO 30 mins IP when tool open HP 1900
10 3380-3460 VO 55 mins No measurable blow Rec 160' M
11 3390-3425 VO 30 mins Shut in 10 mins Faint puff HP 1950 SIP 1500 BHFP 0

No CORES

No PERFS

1 2650-2675 VO 90 SI 60/90 GTS
TSTM Rec 650' mdy, gsy W HP 1
FP 85-322 SIP 92-888
2 2960-3032 VO 90 SI 60/90 Re
gsy M, 150' mdy, gsy sli slty W
1621 FP 35-121 SIP 1083-102
3 3335-3375 VO 23 SI 60/0 Rec
HP 1858-1823 FP 19 29 SIP 8
4 3220-3270 VO 90 SI 60/90 Re
wtry M 2850' SW HP 1760
1187-1378 SIP 1878 1878

12 of


3200
3000
3400
3700
3800
3900
4000
4100
4200
4000
4100
4200
4300
4400
4500
Kbm
Jsw (ribbon sand)
Jsw (shale)
Jr
Jsh
Miss

s

s

2675 VO 90 SI 60/90 GTS in 2 mins
Rec 650' mdy, gsy W HP 1490-1432
322 SIP 92-888
3032 VO 90 SI 60/90 Rec 60' wtry,
M, 150' mdy, gsy sli slty W HP 1621
FP 35-121 SIP 1083-1021
3375 VO 23 SI 60/0 Rec 5' drlg M
858-1823 FP 19-29 SIP 85-NR
3270 VO 90 SI 60/90 Rec 300' gsy,
M 2850' SW HP 1760-1738 FP
1378 SIP 1878-1878

No CORES

No PERFS

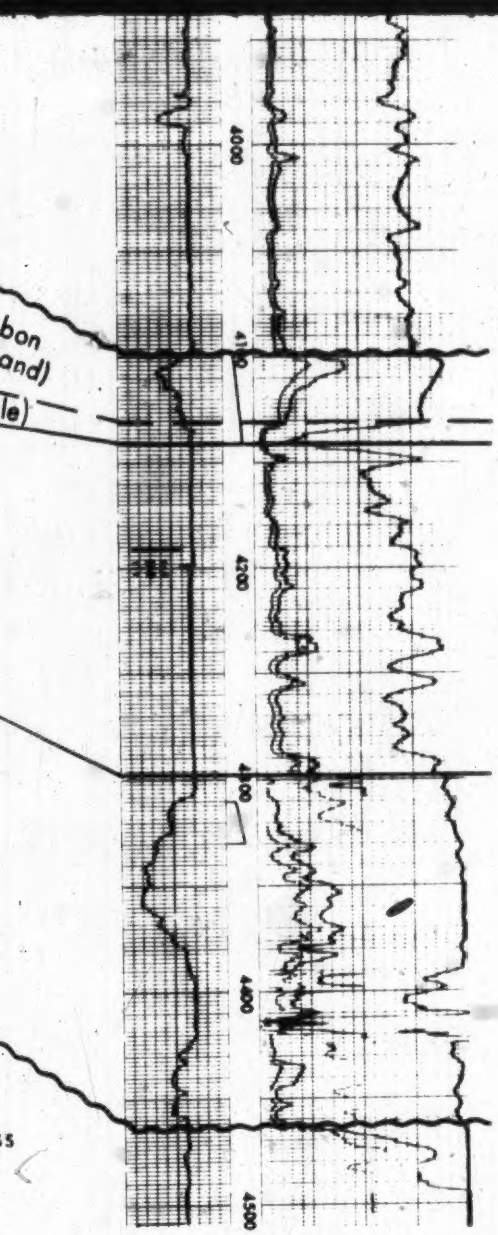
1 4000-50 (Sawt) VO 10/60 SI 60/60 SAB thru, NGTS Rec 3350' fr W HP 1997-1985 FP 567-1276 SIP 1637-1618

No CORES

No PERFS

6 4310-4330 (Upr Sawtooth Sand) VO 15/60 SI 60/90 GTS in 55 min, TSTM, Rec 3780' W HP 2328-2316 FP 1233-2316 SIP 1679-1689
7 4098-4114 (Sunburst) VO 15/60 SI 60/90 Rec 60' wtry M, 100' W HP 2222-2193 FP 53-77 SIP 1451-1162

13 of

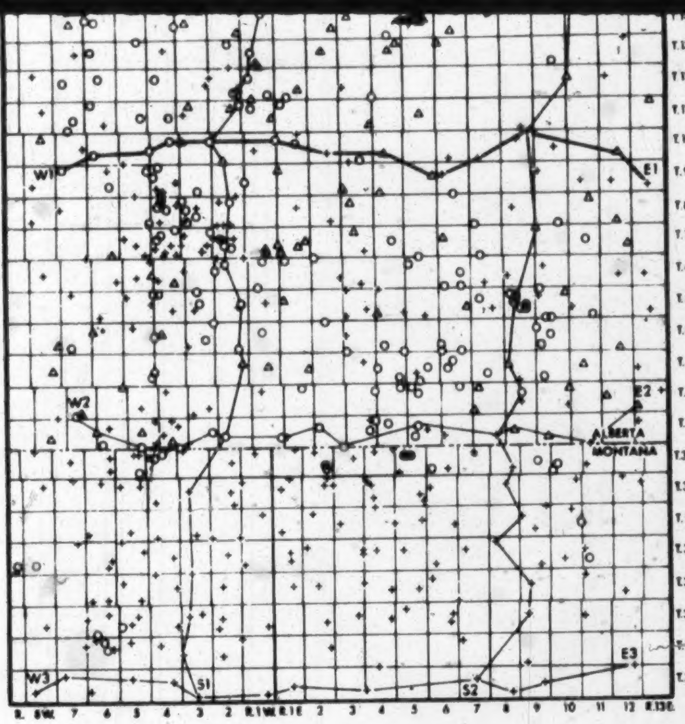


No CORES

No PERFS

6 4310-4330 (Upr Sawtooth Sand) VO 15 60 SI 60/90 GTS in 55 min, TSTM, Rec 3780' W. HP 2328-2316 FP 1233-2316 SIP 1679-1689

7 4098-4114 (Sunburst) VO 15/60 SI 60/90 Rec 60' wtry M, 100' W HP 2222-2193 FP 53-77 SIP 1461-1162


W1
E1
W2
E2
W3
S1
S2
E3
ALBERTA
MONTANA
T.13
T.12
T.11
T.10
T.9
T.8
T.7
T.6
T.5
T.4
T.3
T.2
T.1
T.37N.
T.36N.
T.35N.
T.34N.
T.33N.
T.32N.
T.31N.
T.30N.
R. 8W.
7
6
5
4
3
2
R.1W.
R.1E.
2
3
4
5
6
7
8
9
10
11
12
R.13E.

CROSS SECTION LOCATION MAP
SOUTHEASTERN ALBERTA-NORTHERN MONTANA

0 5 10 15 20 25 30
MILES (Approx.)

14 of 14

FIGURE 9

STRATIGRAPHIC CROSS SECTION
W1-E1

DATUM: 600 feet below Base of Fish Scales

B. Hayes
University of Alberta
1981

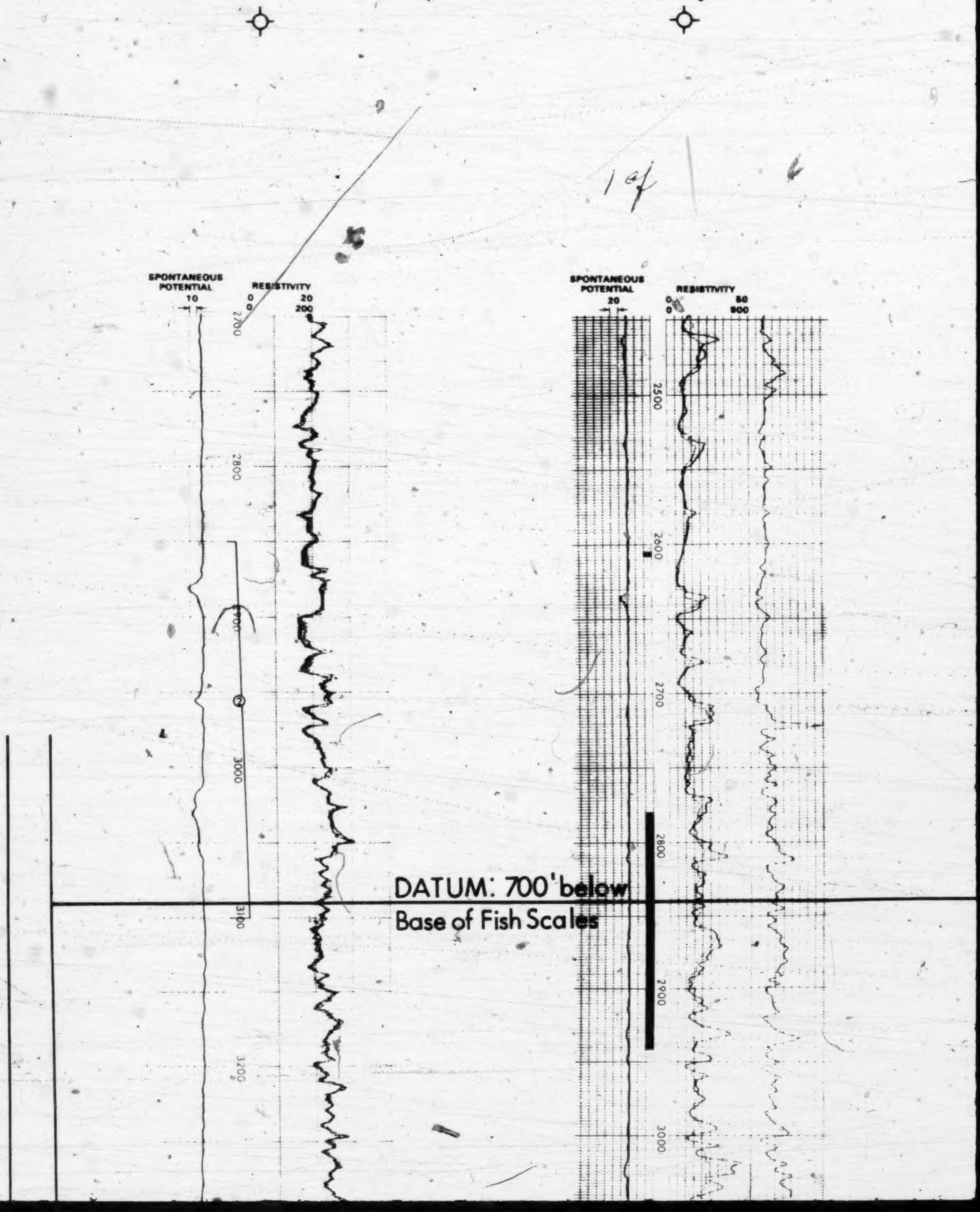
VERTICAL SCALE: 1"= 80 ft.

W 2

WESTCOAST
Twin River 14-33
14-33-1-19W4
KB 3880' (1182.9m) TD 4924' (1501.1m)

WESTERN DOME - SOC.
Border 3-19
3-19-1-18W4
KB 3901' (1192.4m) TD 3937' (1200.3m)

KB 3

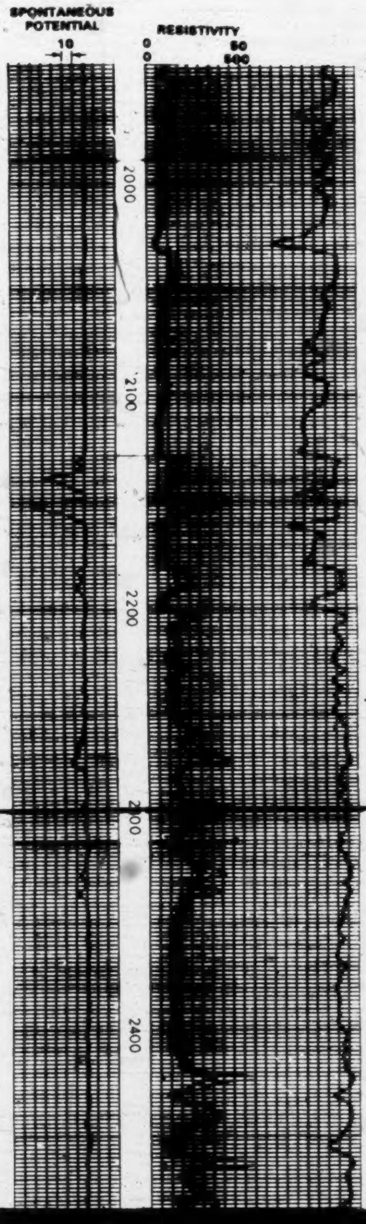

1 of
SPONTANEOUS POTENTIAL
10
RESISTIVITY
0 20
0 200
2700
2800
2900
2
3000
3100
3200
SPONTANEOUS POTENTIAL
20
RESISTIVITY
0 50
0 500
2500
2600
2700
2800
2900
3000
DATUM: 700' below
Base of Fish Scales

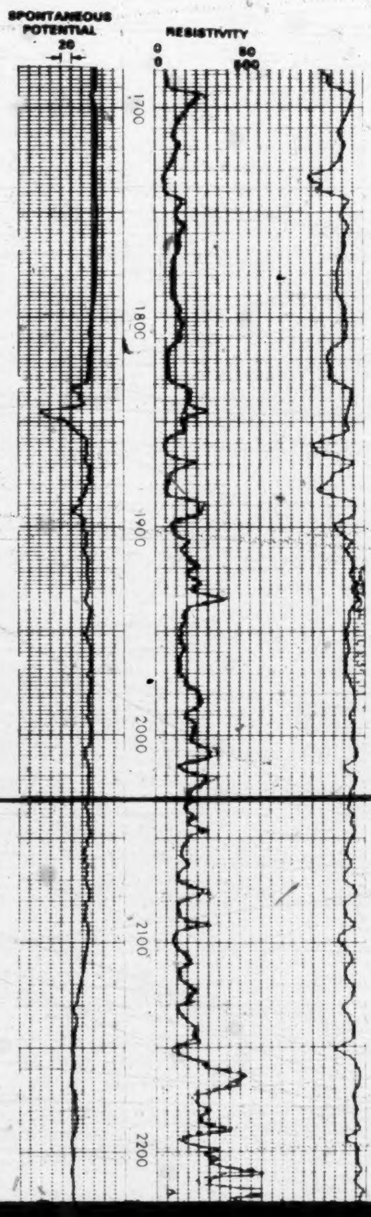
DECALTA
Milk River 2-4
2-4-1-17W4
KB 3808' (1161.0m) TD 2914' (888.5m)

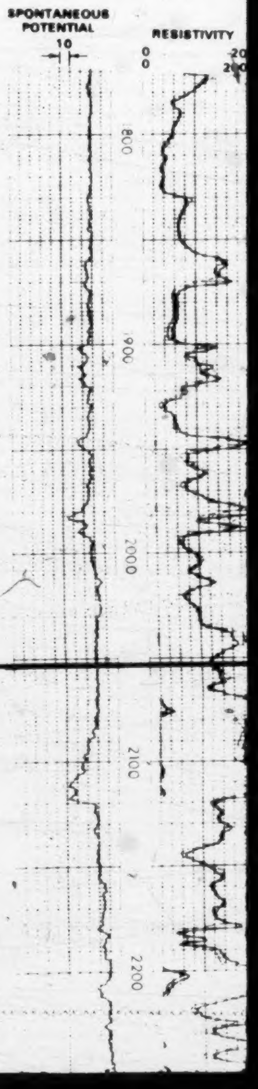
UNION - BUCKLEY
Nose 4-2
4-2-1-16W4
KB 3512' (1070.8m) TD 2527' (770.5m)

CABEEN
Coutts 11-23
11-23-1-15W4
KB 3415' (1041.2m) TD 2574'

2 of





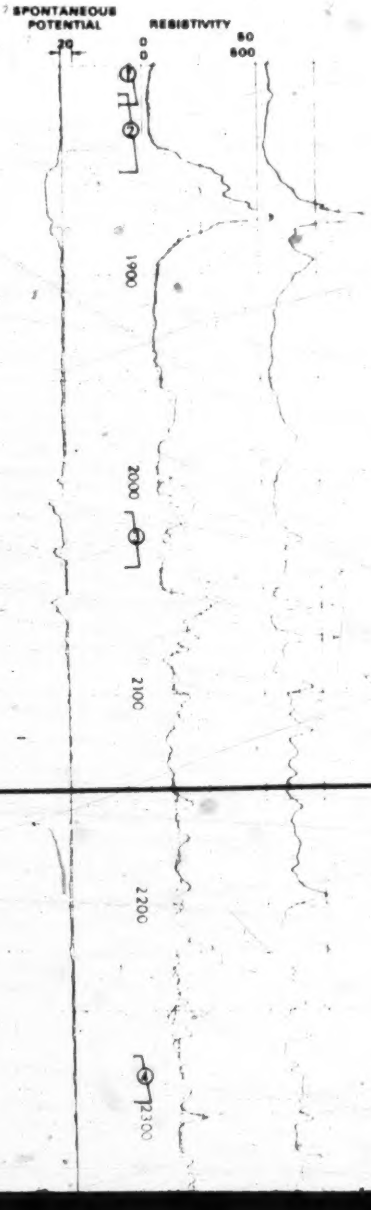


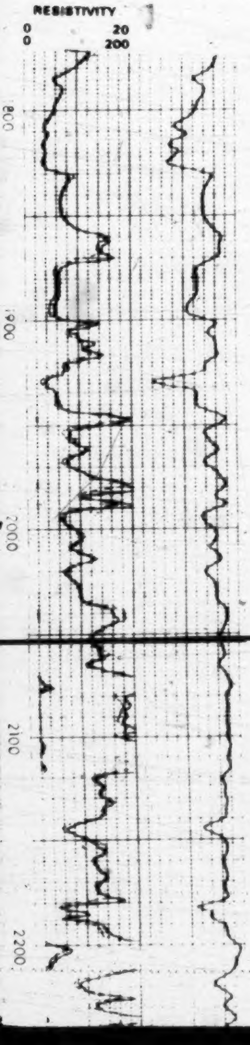
EEN
11-23
-15W4
TD 2574' (784.9m)

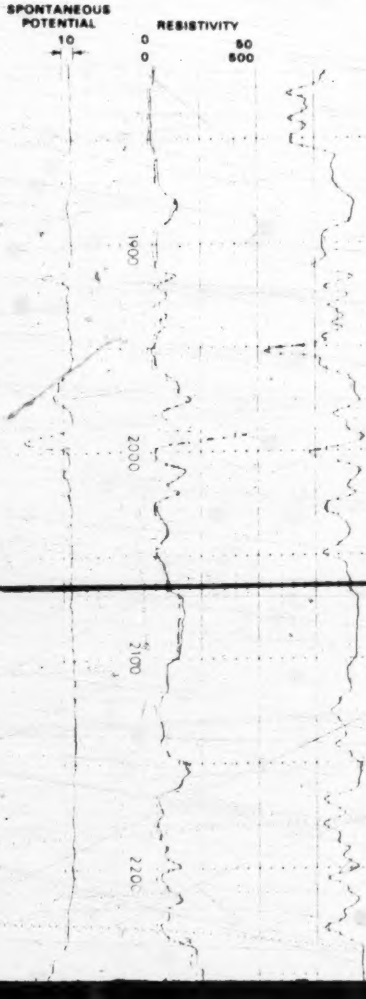
UNION
Coutts 7-18
7-18-1-14W4
KB 3465' (1056.4m) TD 4279' (1304.5m)

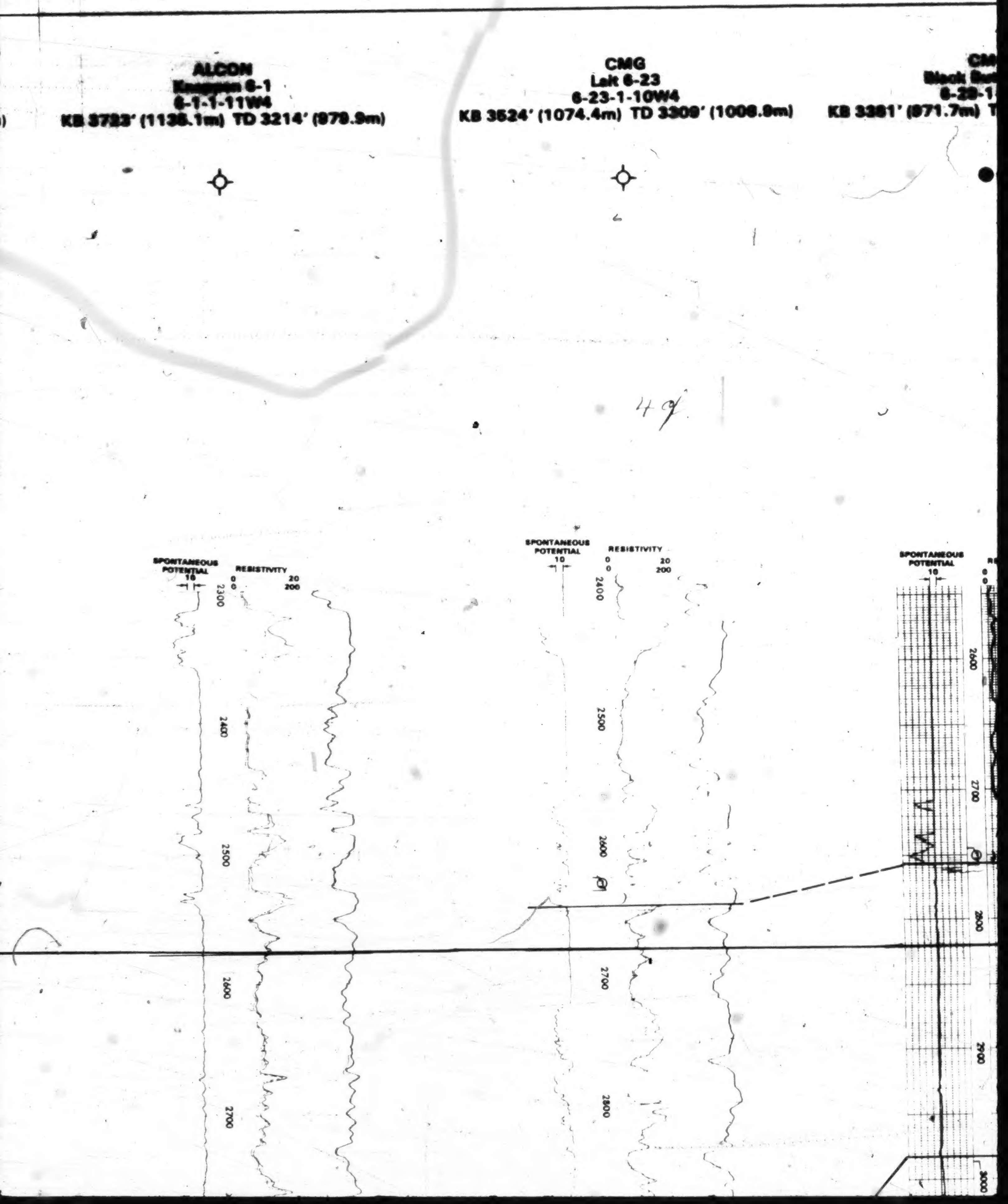
CROSSI
Knappen 7-18
7-18-1-12W4
KB 3539' (1079.0m) TD 2644' (806.2m)

3 aj

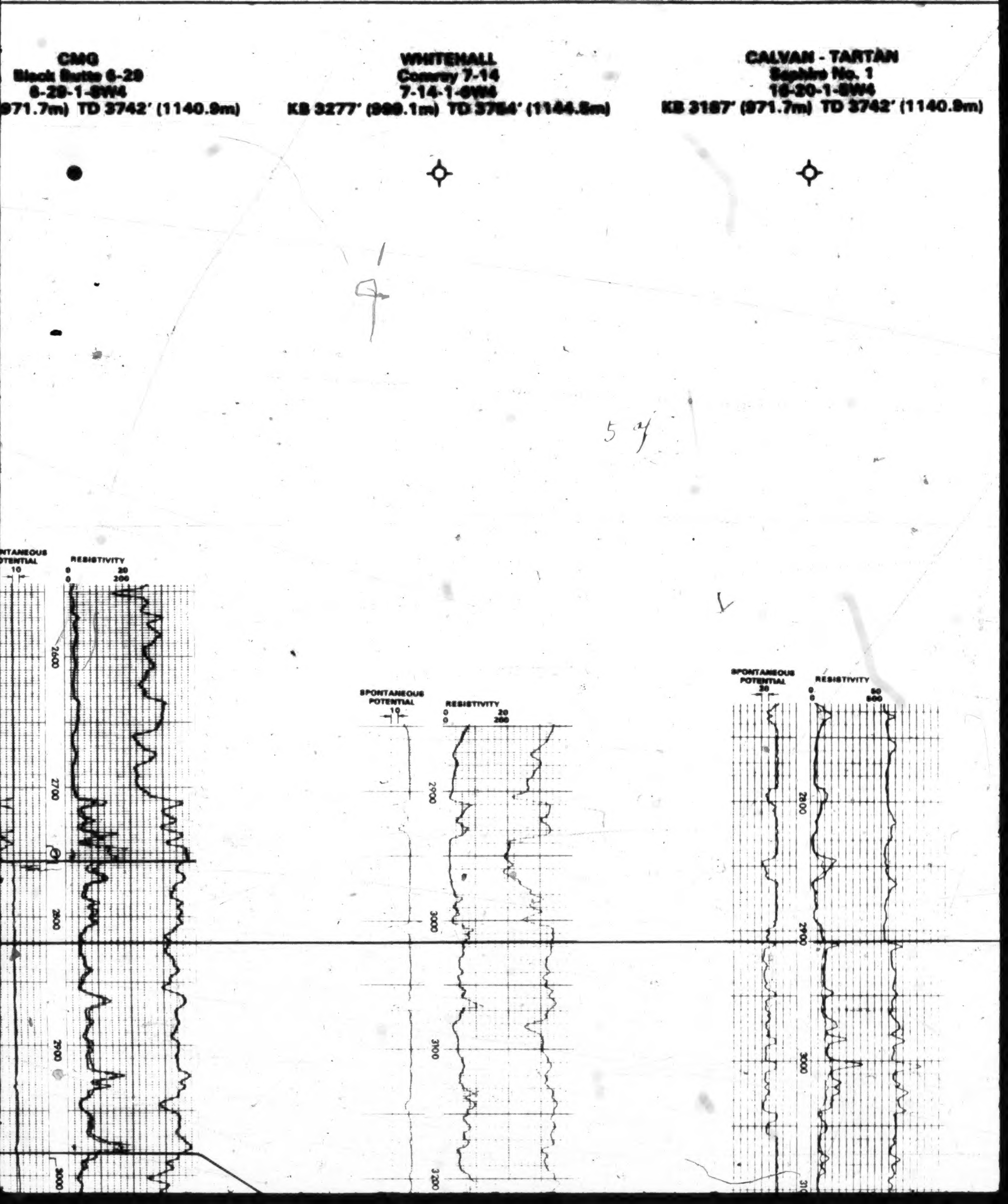







ALCON
Knappen 6-1
6-1-1-11W4
KB 3723' (1135.1m) TD 3214' (979.9m)
CMG
Lalt 6-23
6-23-1-10W4
KB 3524' (1074.4m) TD 3309' (1008.9m)
CM
Black Bu
6-29-1
KB 3381' (971.7m) T
SPONTANEOUS POTENTIAL
10
RESISTIVITY
0 20
0 200
2300
2400
2500
2600
2700
SPONTANEOUS POTENTIAL
10
RESISTIVITY
0 20
0 200
2400
2500
2600
2700
2800
SPONTANEOUS POTENTIAL
10
2600
2700
2800
2900
3000

49


CMG
Black Butte 6-29
6-29-1-5W4
971.7m) TD 3742' (1140.9m)
WHITEHALL
Conrey 7-14
7-14-1-5W4
KB 3277' (999.1m) TD 3754' (1144.5m)
CALVAN - TARTAN
Saphire No. 1
16-20-1-5W4
KB 3187' (971.7m) TD 3742' (1140.9m)
NTANEOUS
TENTIAL
10
RESISTIVITY
0 20
0 200
2600
2700
2800
2900
3000
SPONTANEOUS
POTENTIAL
10
RESISTIVITY
0 20
0 200
2900
3000
3100
3200
SPONTANEOUS
POTENTIAL
30
RESISTIVITY
0 50
0 500
2800
2900
3000
310

1

9

5 of

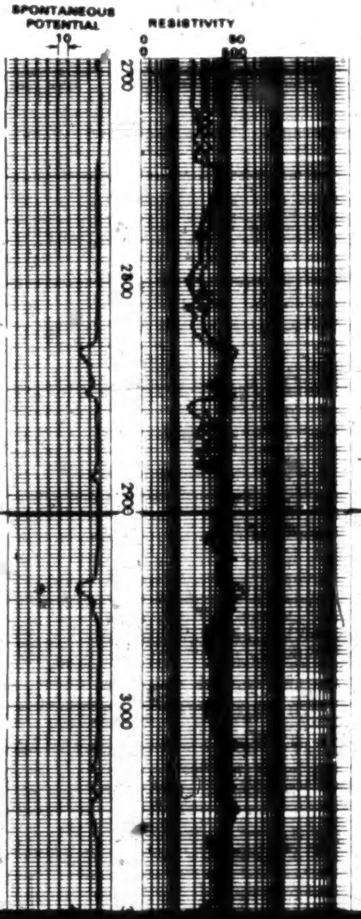
40.9m)

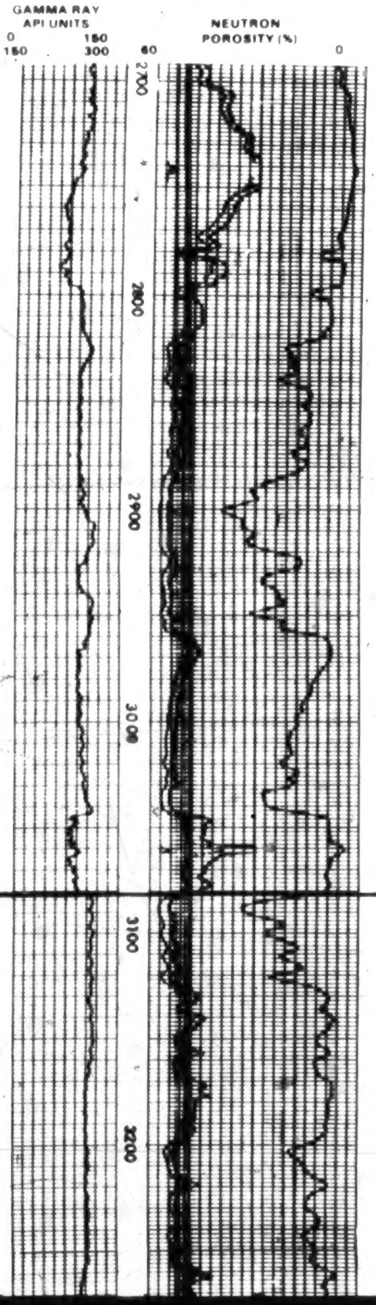
PAC. - AMOCO
One Four 1-4
6-16-1-4W4
KB 2917' (889.4m) TD 3671' (1119.2m)

CMG
Bain 6-2
6-2-1-3W4
KB 2875' (876.6m) TD 3964' (1208.5m)

B
Sage
10
KB 2911' (887.6

6 of

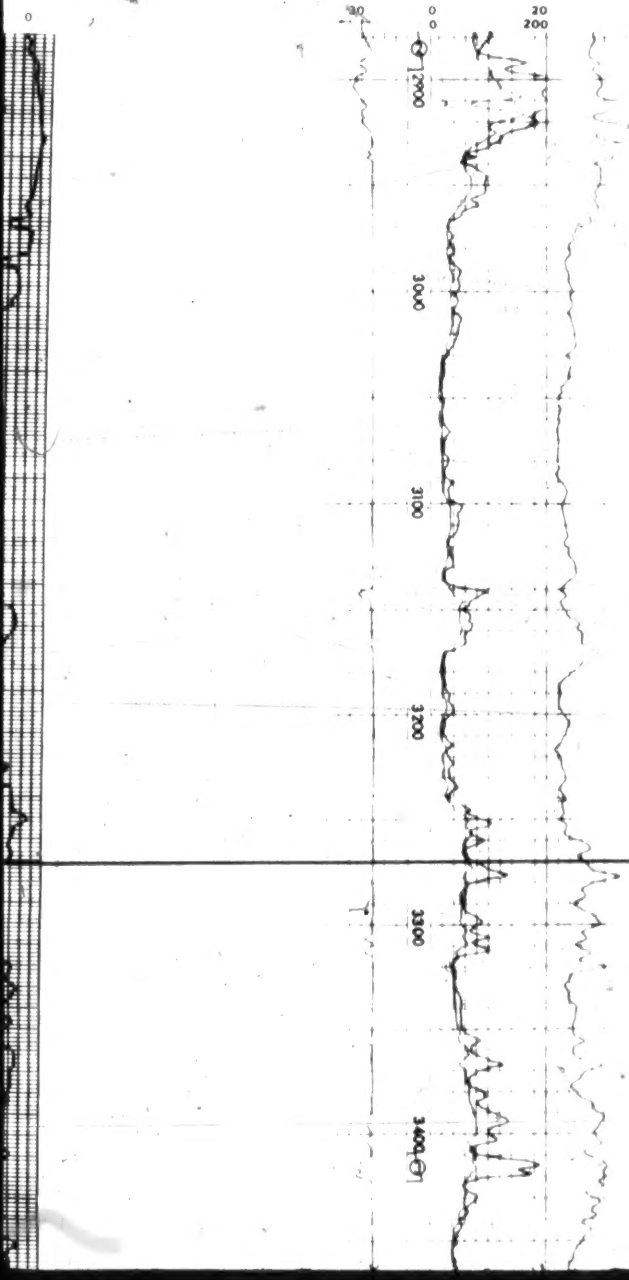




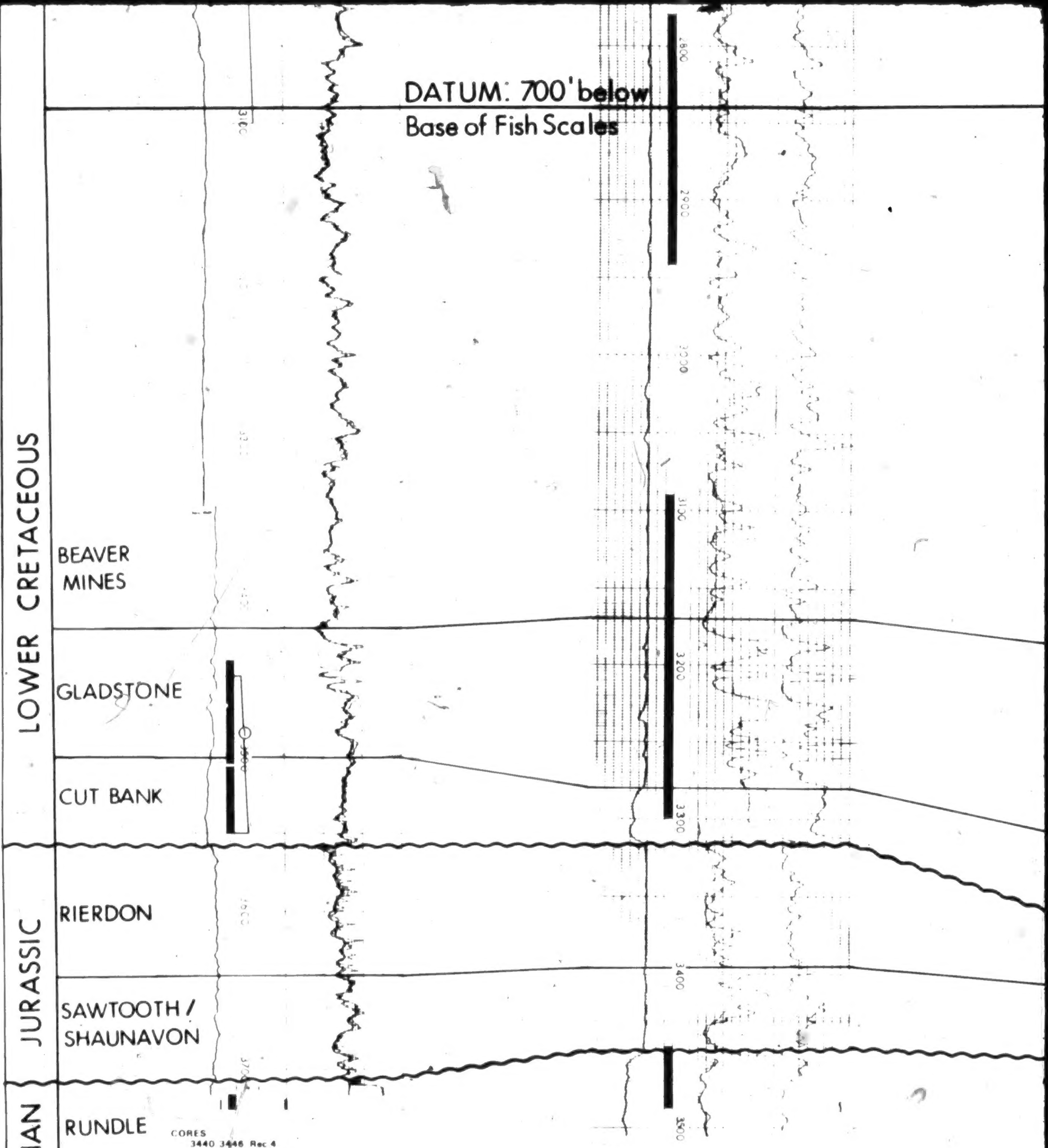
E 2

1208.5m)

B.A. - H.B.
Sage Creek 10-8
10-8-2-1W4
KB 2911′ (887.6m) TD 3948′ (1203.7m)



DATUM: 700′ below
Base of Fish Scales


DATUM: 700' below
Base of Fish Scales
LOWER CRETACEOUS
BEAVER MINES
GLADSTONE
CUT BANK
JURASSIC
RIERDON
SAWTOOTH / SHAUNAVON
MISSISSIPPIAN
RUNDLE
3100
3600
3700
2800
2900
3000
3100
3200
3300
3400
3500

CORES
3440 3446 Rec 4
3446 3506 Rec 60
3508 3550 Rec 42
3716 3749 Rec 33
3750 3752 Rec 1

No PERFS

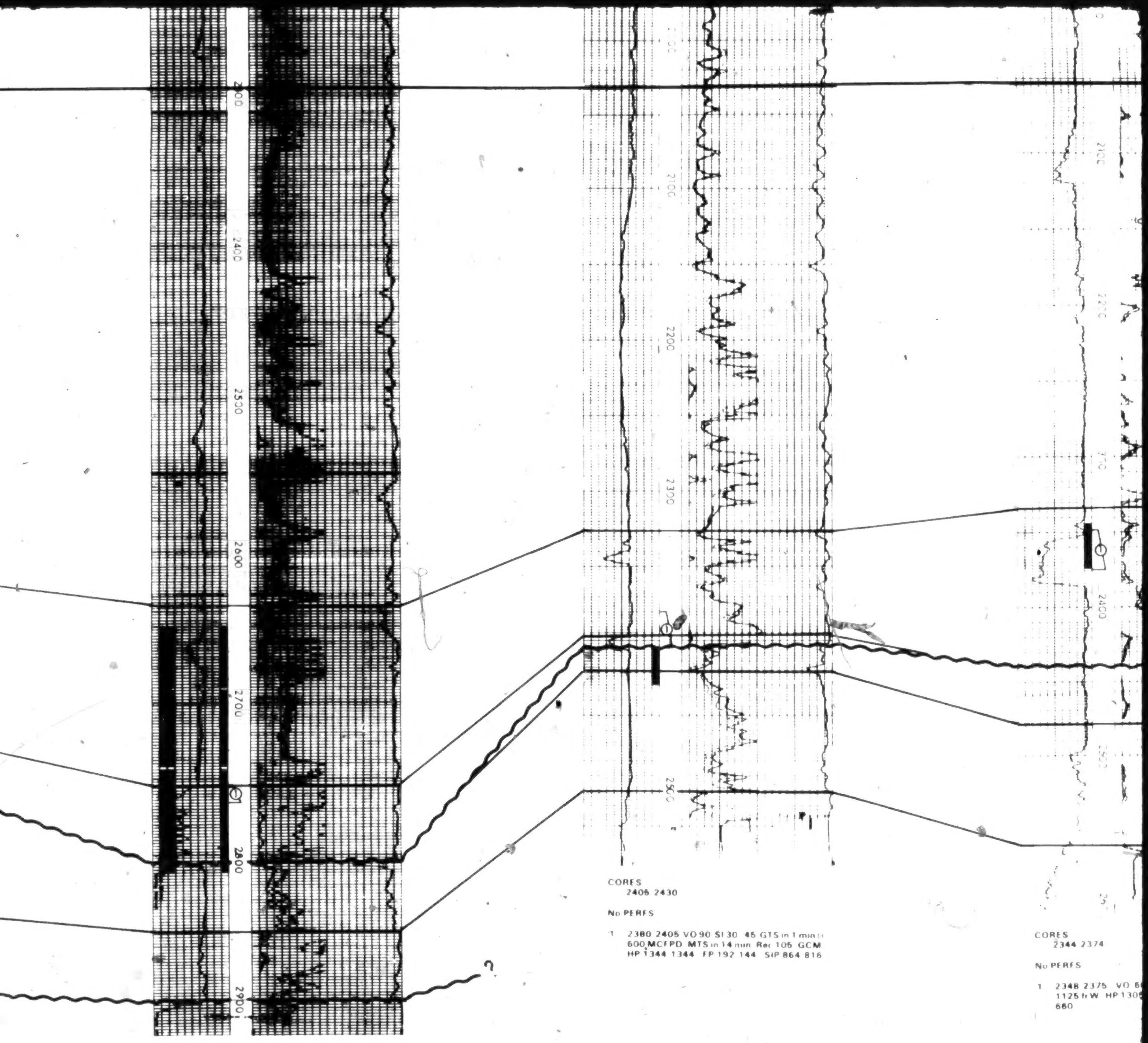
1 3460 3550 (Cutbank) VO 20/60 SI 60 120 GAB died in 45 mins Rc 800' MC fr W HP 1396 1596 FP 1140 1155 SIP 1145 1180
2 2850 3100 Misrun pkr seat failed

CORES
2143 2210 2605 08
2780 2941 3090 3299
3448 87

No PERFS

1 2180 97 Misrun
2 2185 2210 No Time Rec 10' M
3 2215 49 VO 60' Rec 10' M
4 2608 42 VO 5 Rec 250' M
5 3268 99 VO 45 Rec 720' fr W
6 3490 3510 VO 30 sl air blow Rec 1710 sul W HP 1650
7 3150 78 VO 45 Rec 10' M
8 3228 36 VO 60 Rec 20' M HP 700
9 3442 55 VO 60 SAB Rec 1035' sul W

8 of



CORES
2660 2690 2692 2742
2745 2811

No PERFS

1 2756 2766 VO 36 SI 60 60 Rec 4 M HP
1646 1653 FP 39 47 SIP 902 1012

CORES
2406 2430

No PERFS

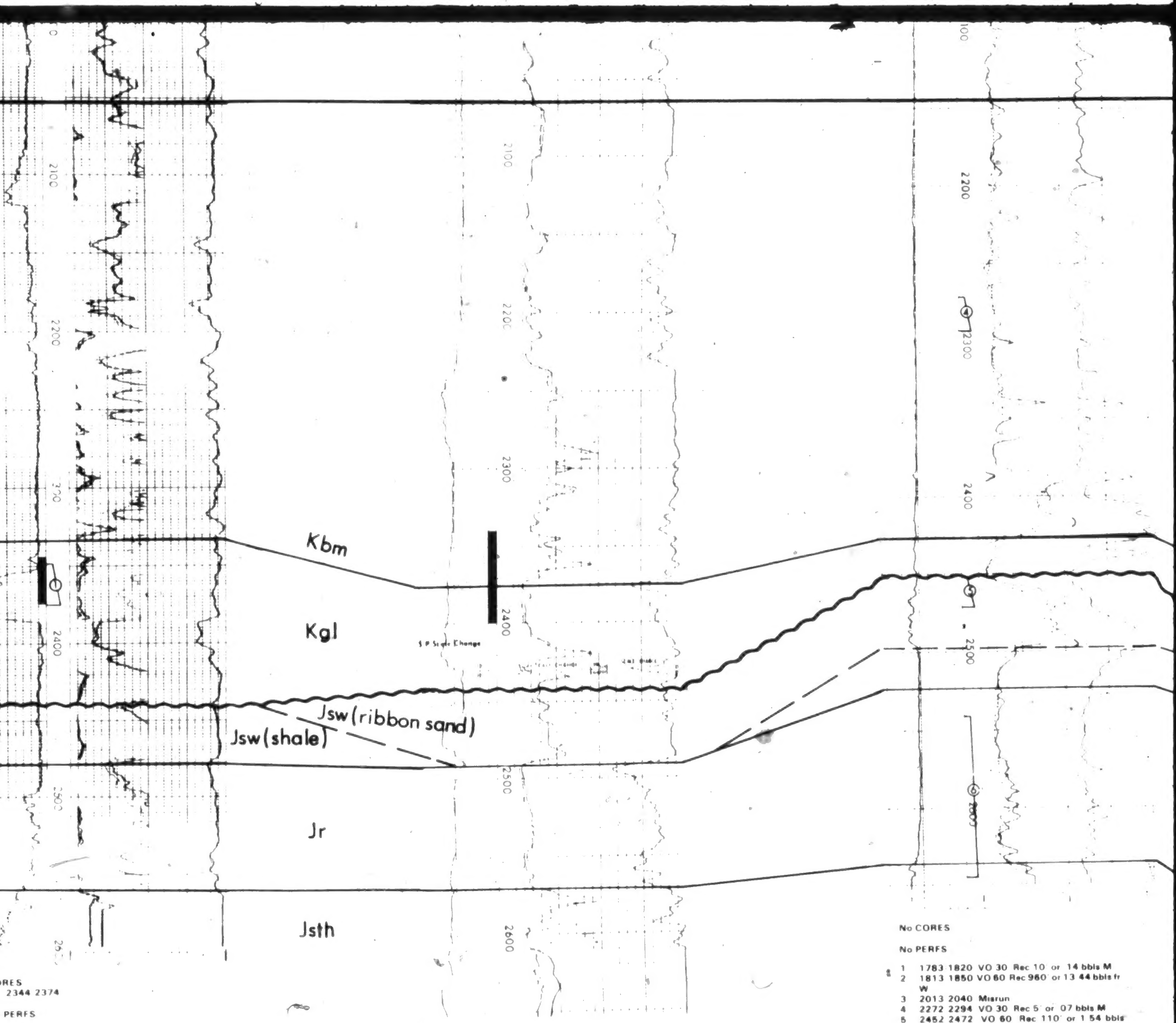
1 2380 2405 VO 90 SI 30 45 GTS in 1 min
600 MCFPD MTS in 14 min Rec 106 GCM
HP 1344 1344 FP 192 144 SIP 864 816

CORES
2344 2374

No PERFS

1 2348 2375 VO 6
1125 ft W HP 1305
660

9 of


Kbm
Kgl
Jsw(ribbon sand)
Jsw(shale)
Jr
Jsth
S P Scale Change
2100
2200
2300
2400
2500
2600
100

ORES
2344 2374

PERFS

2348 2375 VO 60 SI 15 15 mins Rec 1125 fr W HP 1305 1305 FP 200 470 FSIP 660

CORES
2340 2400

No PERFS

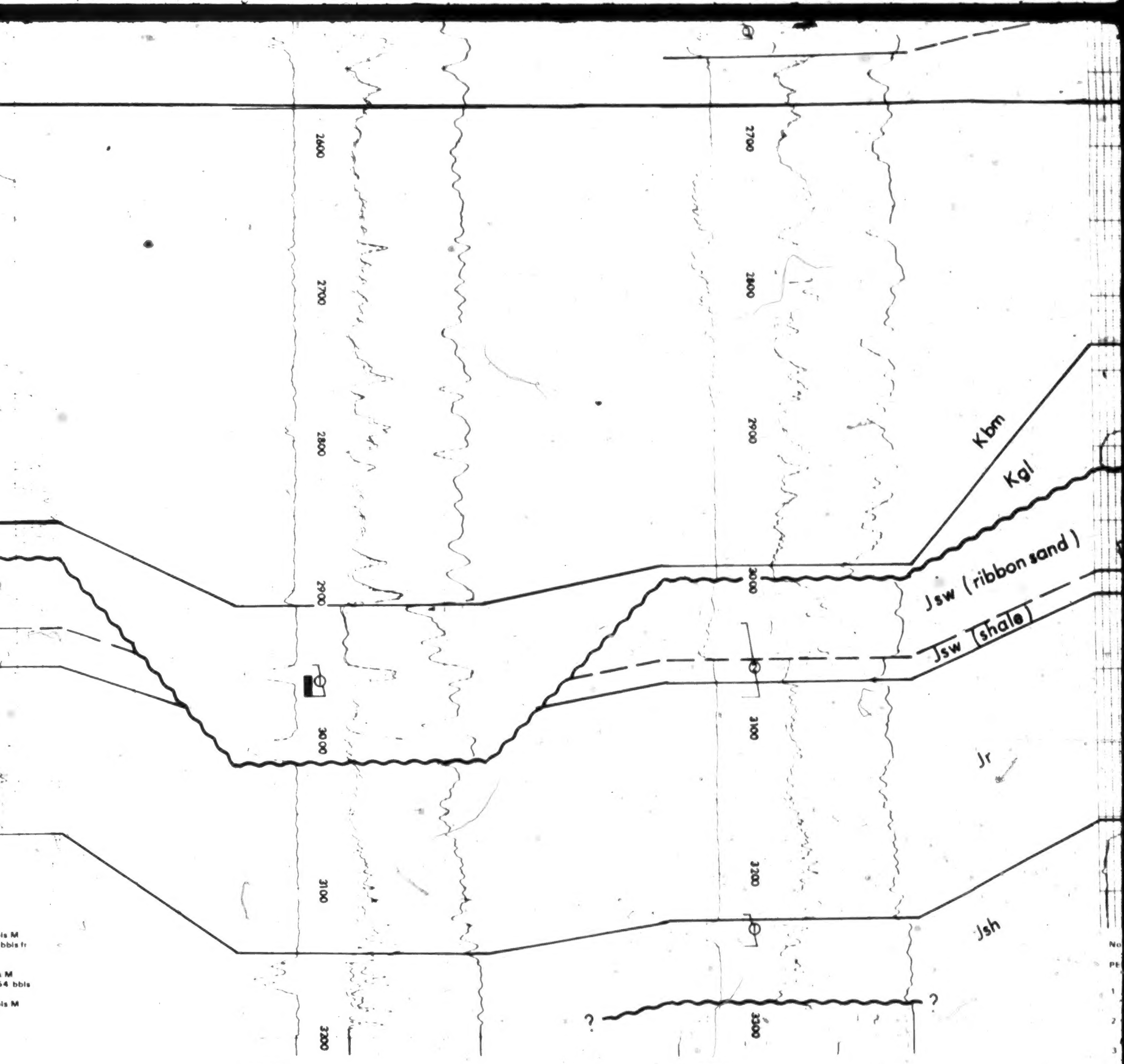
No DST

No CORES

No PERFS

1 1783 1820 VO 30 Rec 10 or 14 bbls M
2 1813 1850 VO 60 Rec 960 or 13 44 bbls fr W
3 2013 2040 Misrun
4 2272 2294 VO 30 Rec 5 or 07 bbls M
5 2452 2472 VO 60 Rec 110 or 1 54 bbls mdy W
6 2541 2571 VO 10 Rec 10 or 14 bbls M

10 of


2600
2700
2800
2900
3000
3100
3200
2700
2800
2900
3000
3100
3200
3300
Kbm
Kgl
Jsw (ribbon sand)
Jsw (shale)
Jr
Jsh
?
?

ls M
bbls fr

s M
54 bbls

ls M

CORES
2856-2971 (15')

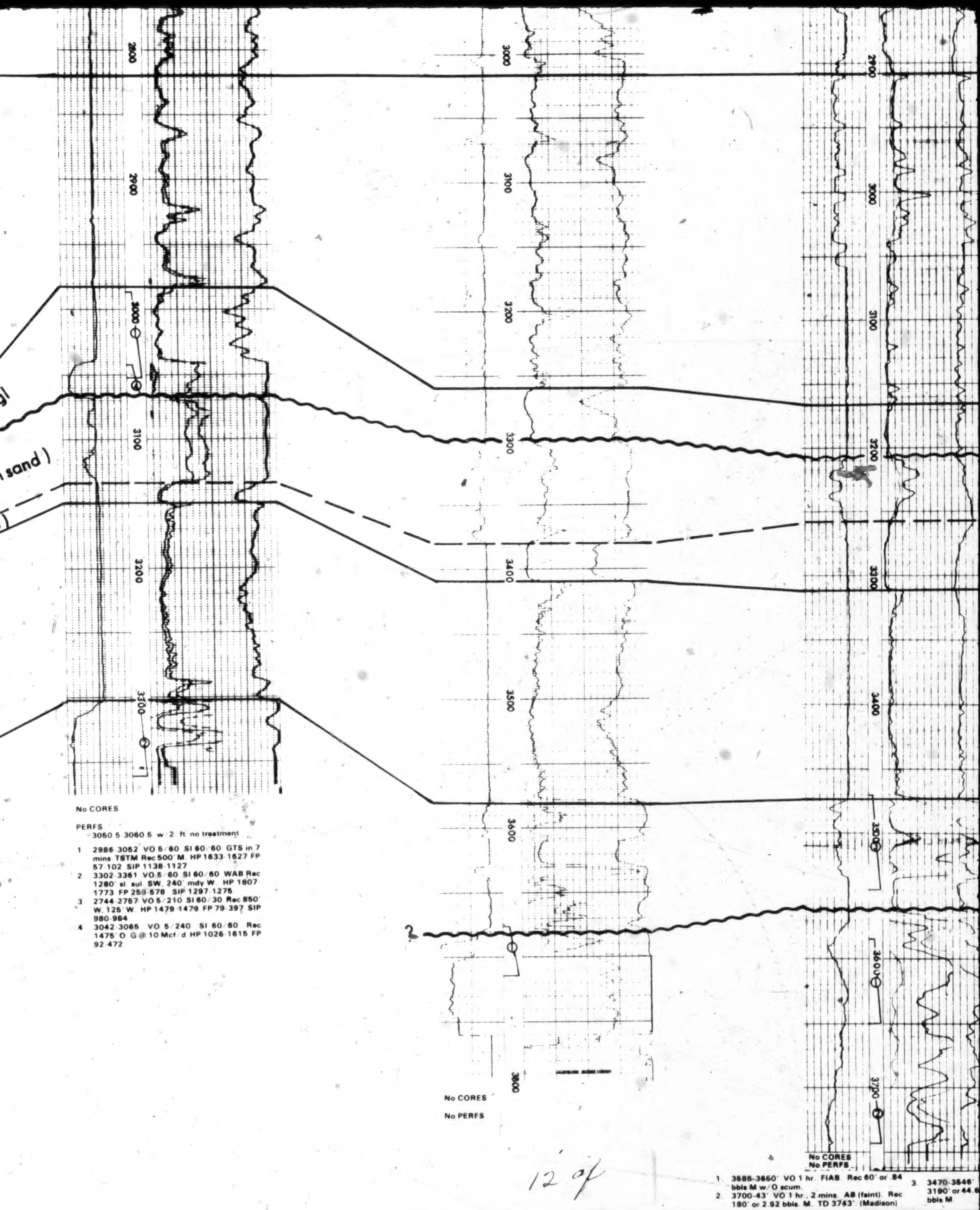
No PERFS

No CORES

No PERFS

1 3228-50 (Sawtooth) VO 5 45 SI 60 30 WAB Reset Rec 5' M HP 1713 1720 FP 22 21 SIP 162 28
2 3030-80 (Blairmore) VO 5 / 30 SI 60 / 30 Rec 60 M HP 1653 1630 FP 50 79 SIP 1061 957
3 2633-44 (Bsl Colo) VO 5 60 SI 60 / 60 Rec 940 W HP 1424 1407 FP 141 409 SIP 899 875

11 of



g)
sand)
2800
2900
3000
3100
3200
3300
3400
3500
3600
3700
3800
2

No CORES

PERFS
3060 5 3060 5 w/2 ft no treatment

1 2986-3052 VO 5/60 SI 60/60 GTS in 7 mins TSTM Rec 500' M. HP 1633-1627 FP 57-102 SIP 1138-1127
2 3302-3361 VO 5/60 SI 60/60 WAB Rec 1280' sl. sul. SW, 240' mdy W. HP 1807-1773 FP 250-578 SIP 1297-1275
3 2744-2757 VO 5/210 SI 60/30 Rec 850' W, 125' W. HP 1479-1479 FP 79-397 SIP 980-964
4 3042-3065 VO 5/240 SI 60/60 Rec 1475' O G @ 10 Mcf/d HP 1026-1615 FP 92-472

No CORES

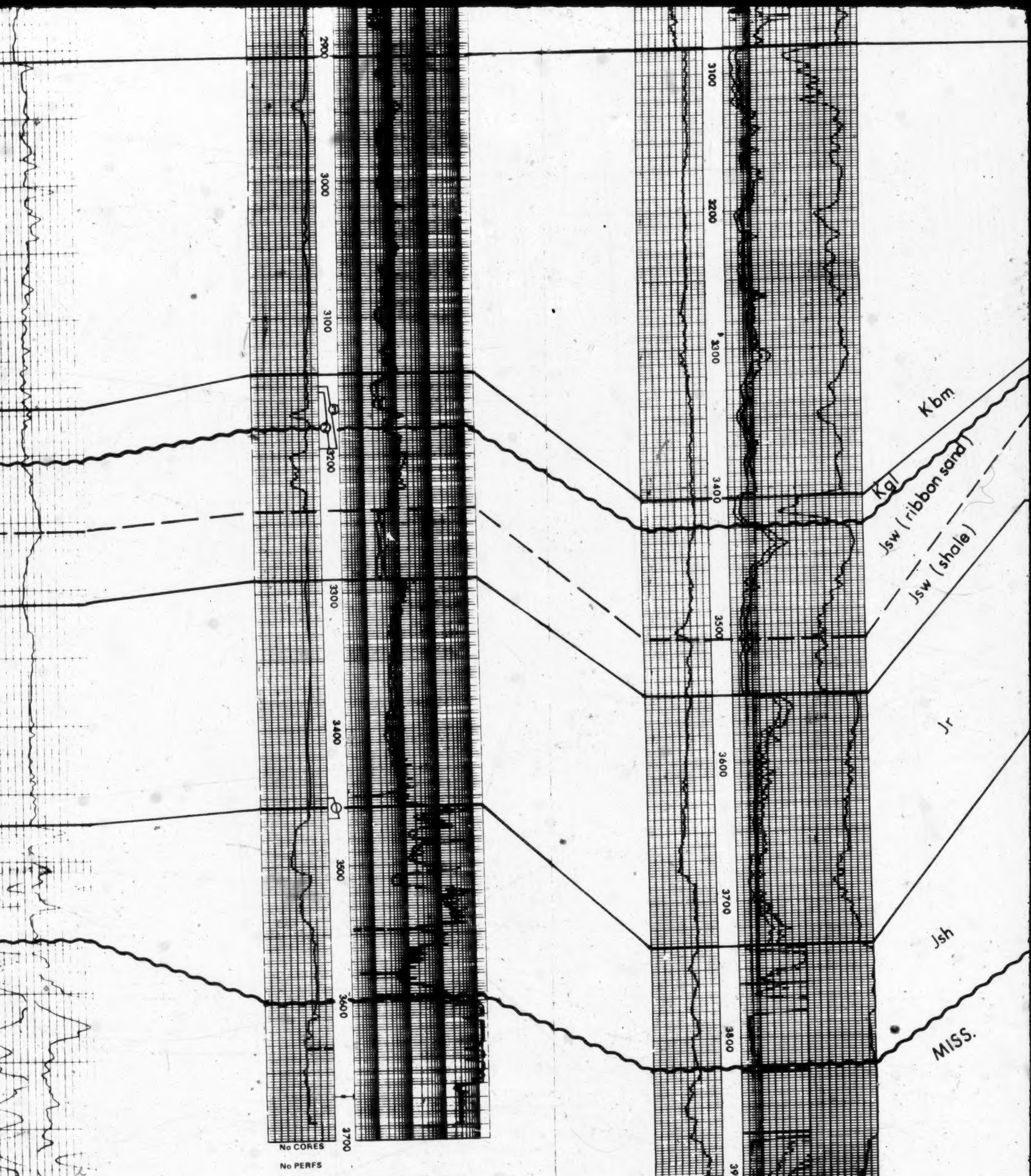
No PERFS

No CORES
No PERFS

1. 3686-3650' VO 1 hr. FIAB. Rec 60' or .84 bbls M w/O scum.
2. 3700-43' VO 1 hr., 2 mins. AB (faint). Rec 180' or 2.52 bbls. M. TD 3743'. (Madison)

3. 3470-3546'
3190' or 44.6
bbls M

12 of



3470-3546' VO 55 mins. No blow. Rec 3190' or 44.66 bbls fairly fr W, & 180' or 2.52 bbls M.

No CORES

No PERFS

1. 3450-65 (Sawtooth) VO 10/60 SI 60/60 on VO FAB decr to WAB. Rec 50' wtry M. HP 1730-1719 FP 30-30 SIP 330-297
2. 3154-95 Misrun
3. 3150-95 (Sunb) VO 5/60 SI 60/60 FAB incr to SAB on VO. GAB thru. Rec 1050' fluid, 300' M, 750' W (1900 ppm NaCl) HP 1563-1552 FP 163-397 SIP 1341-1274

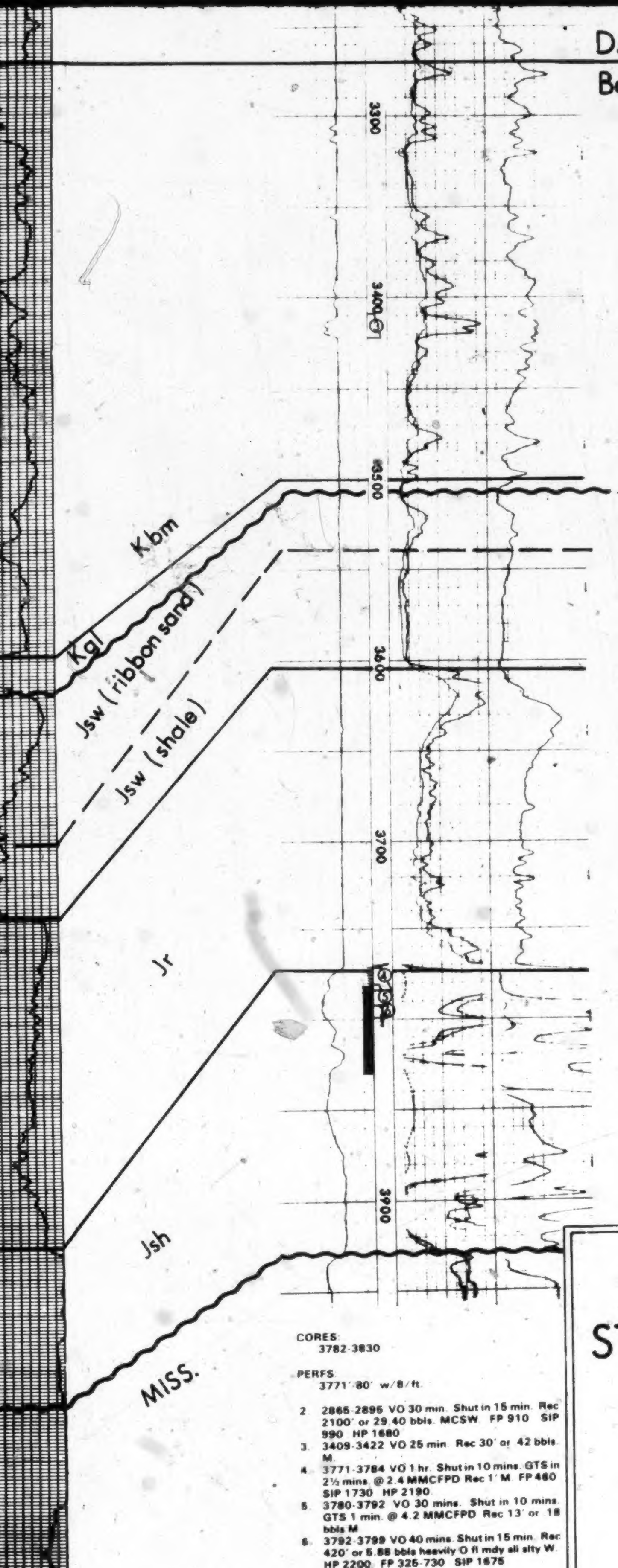
No CORES

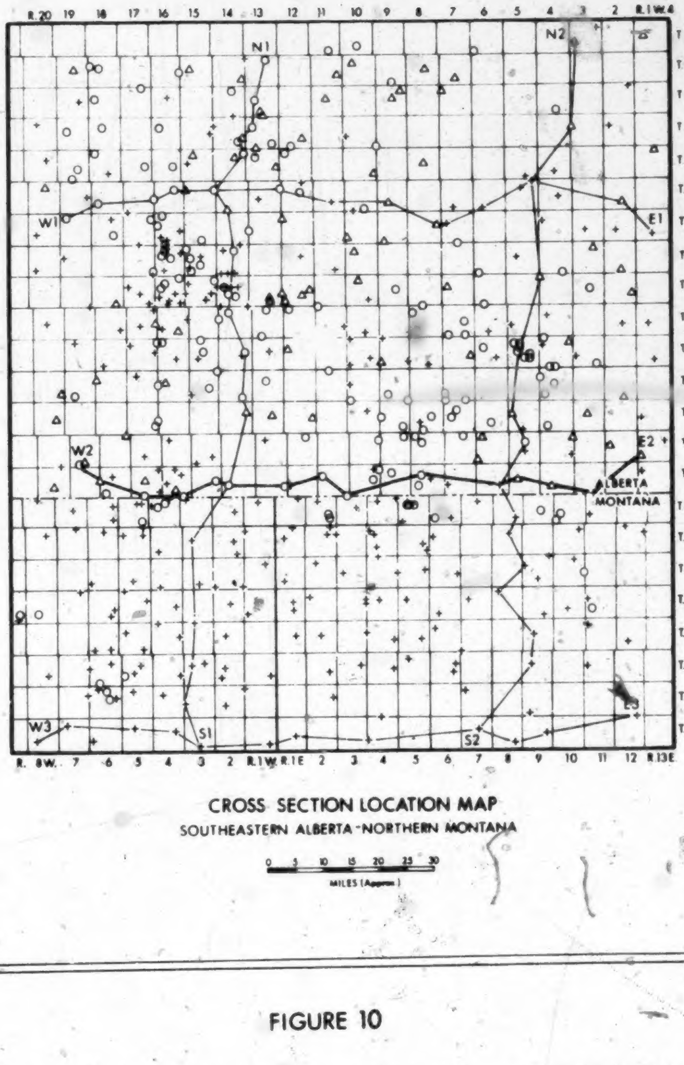
No PERFS

2. 3740-3790 (Sawth) VO 5/60 SI 60/60. GIP. GTS in 1 min. @ 1 MMcf/d. Fair W spray. Rec 620' W. HP 1854-1854 FP 1270-1510 SIP 1764-1756

13 c/

DATUM: 700' below
Base of Fish Scales


3300
3400
3500
3600
3700
3900
Kbm
Kgl
Jsw (ribbon sand)
Jsw (shale)
Jr
Jsh
MISS.


R.20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 R.1W.4
T.15
T.14
T.13
T.12
T.11
T.10
T.9
T.8
T.7
T.6
T.5
T.4
T.3
T.2
T.1
T.37N
T.36N
T.35N
T.34N
T.33N
T.32N
T.31N
T.30N
N1
N2
W1
E1
W2
E2
W3
S1
S2
S3
ALBERTA
MONTANA
R. 8W. 7 6 5 4 3 2 R.1W R.1E 2 3 4 5 6 7 8 9 10 11 12 R.13E

CROSS SECTION LOCATION MAP
SOUTHEASTERN ALBERTA - NORTHERN MONTANA

0 5 10 15 20 25 30
MILES (Approx.)

CORES:
3782-3830

PERFS:
3771'-80' w/8/ft.

2. 2865-2895 VO 30 min. Shut in 15 min. Rec 2100' or 29.40 bbls. MCSW. FP 910 SIP 990 HP 1680
3. 3409-3422 VO 25 min. Rec 30' or .42 bbls. M.
4. 3771-3784 VO 1 hr. Shut in 10 mins. GTS in 2½ mins. @ 2.4 MMCFPD Rec 1' M. FP 460 SIP 1730 HP 2190
5. 3780-3792 VO 30 mins. Shut in 10 mins. GTS 1 min. @ 4.2 MMCFPD Rec 13' or .18 bbls M
6. 3792-3799 VO 40 mins. Shut in 15 min. Rec 420' or 5.88 bbls heavily O fl mdy sli slty W. HP 2200 FP 325-730 SIP 1675

30 GIP.
ry. Rec
510 SIP

FIGURE 10

STRATIGRAPHIC CROSS SECTION
W2-E2

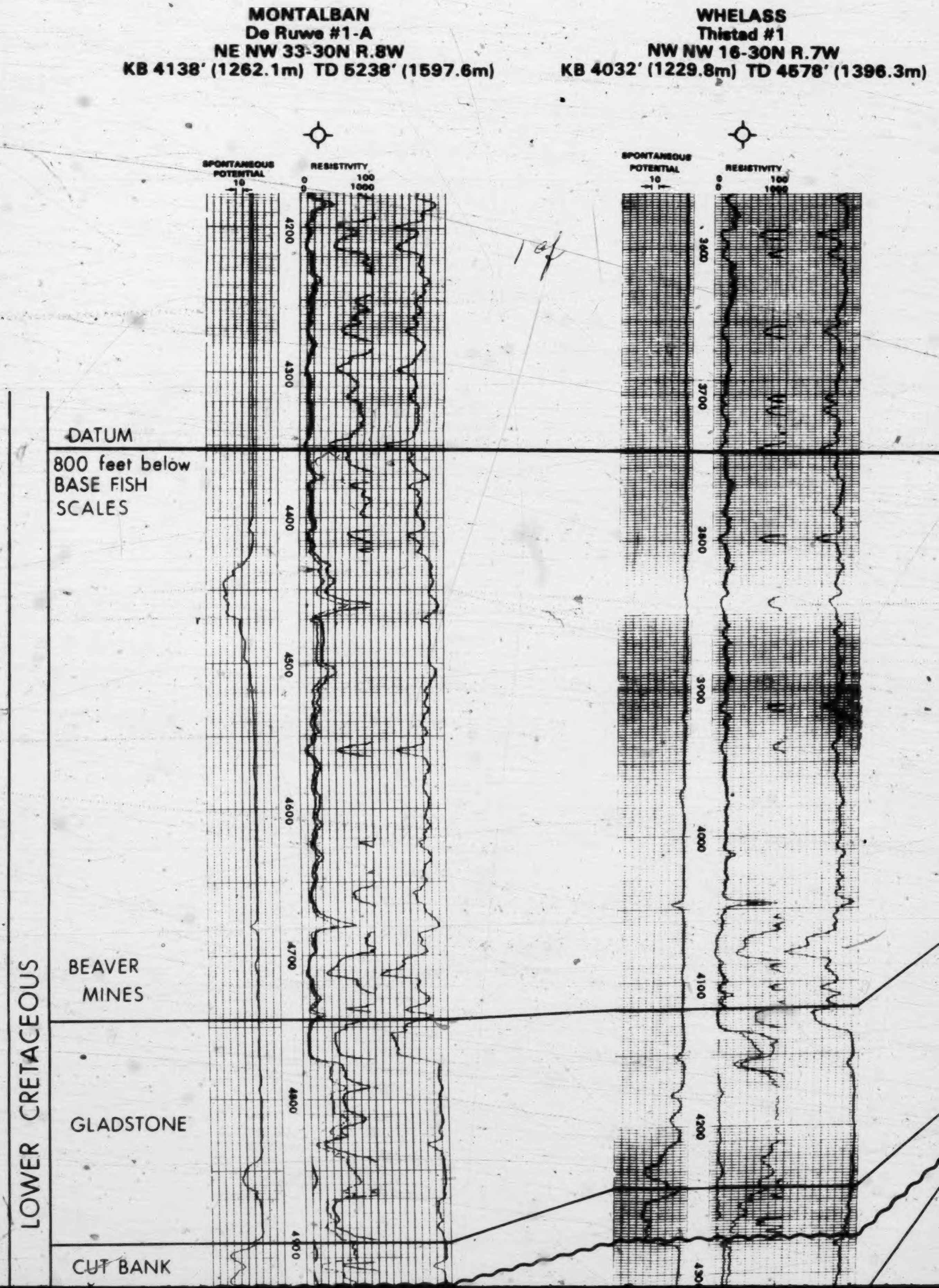
DATUM: 700 feet below Base of Fish Scales.

B. Hayes
University of Alberta
1981

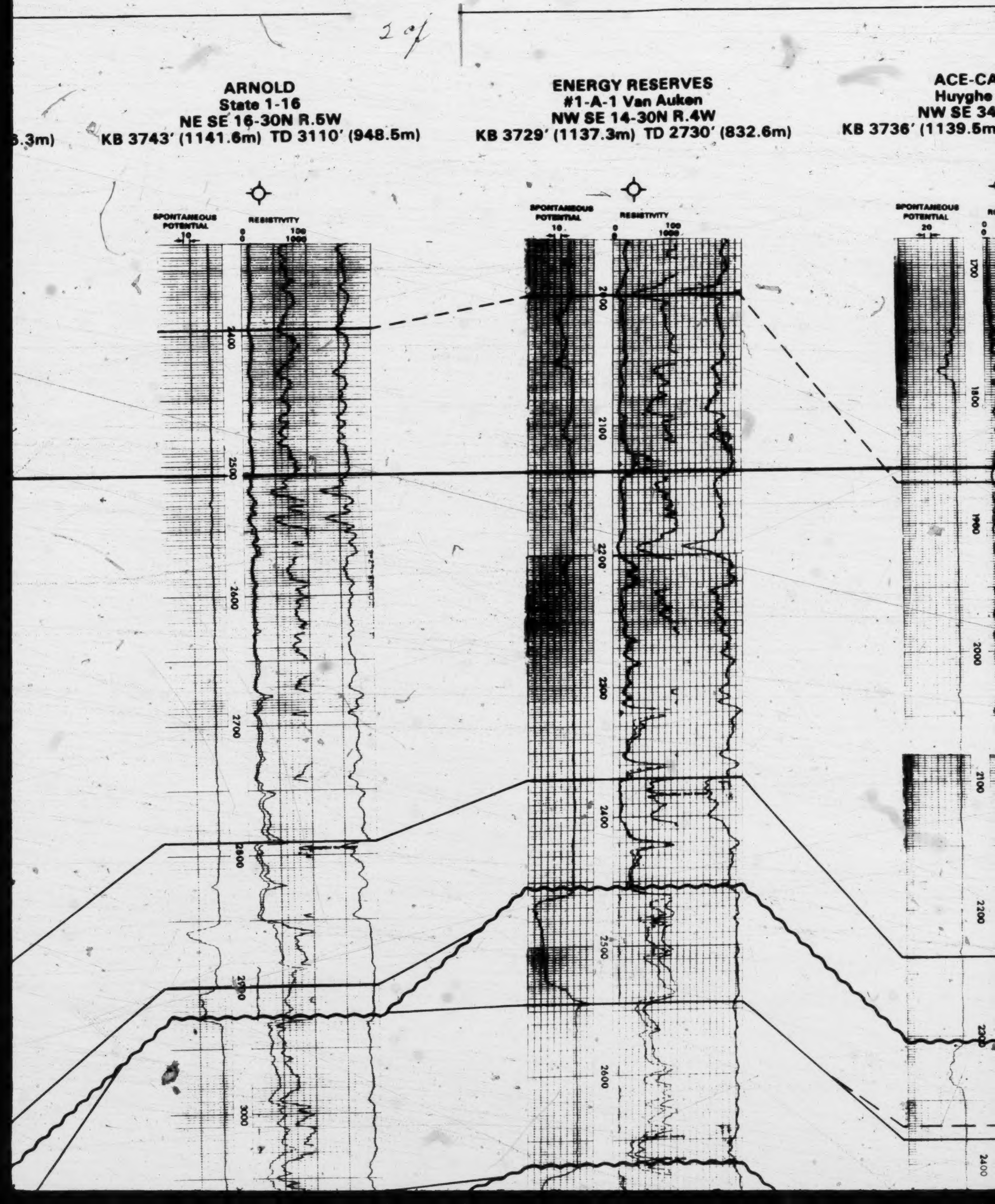
VERTICAL SCALE: 1" = 80'

14 of 14

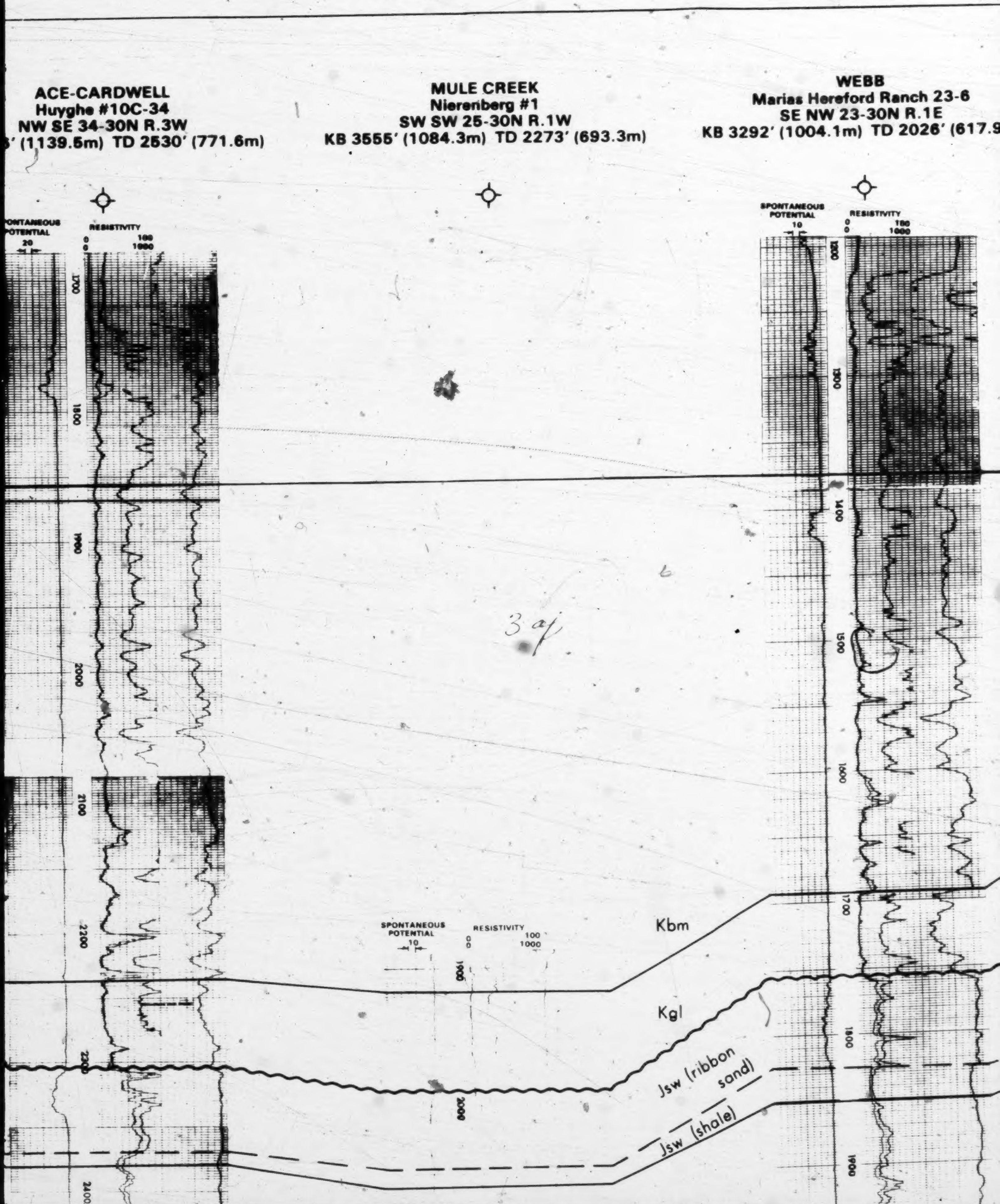
W3

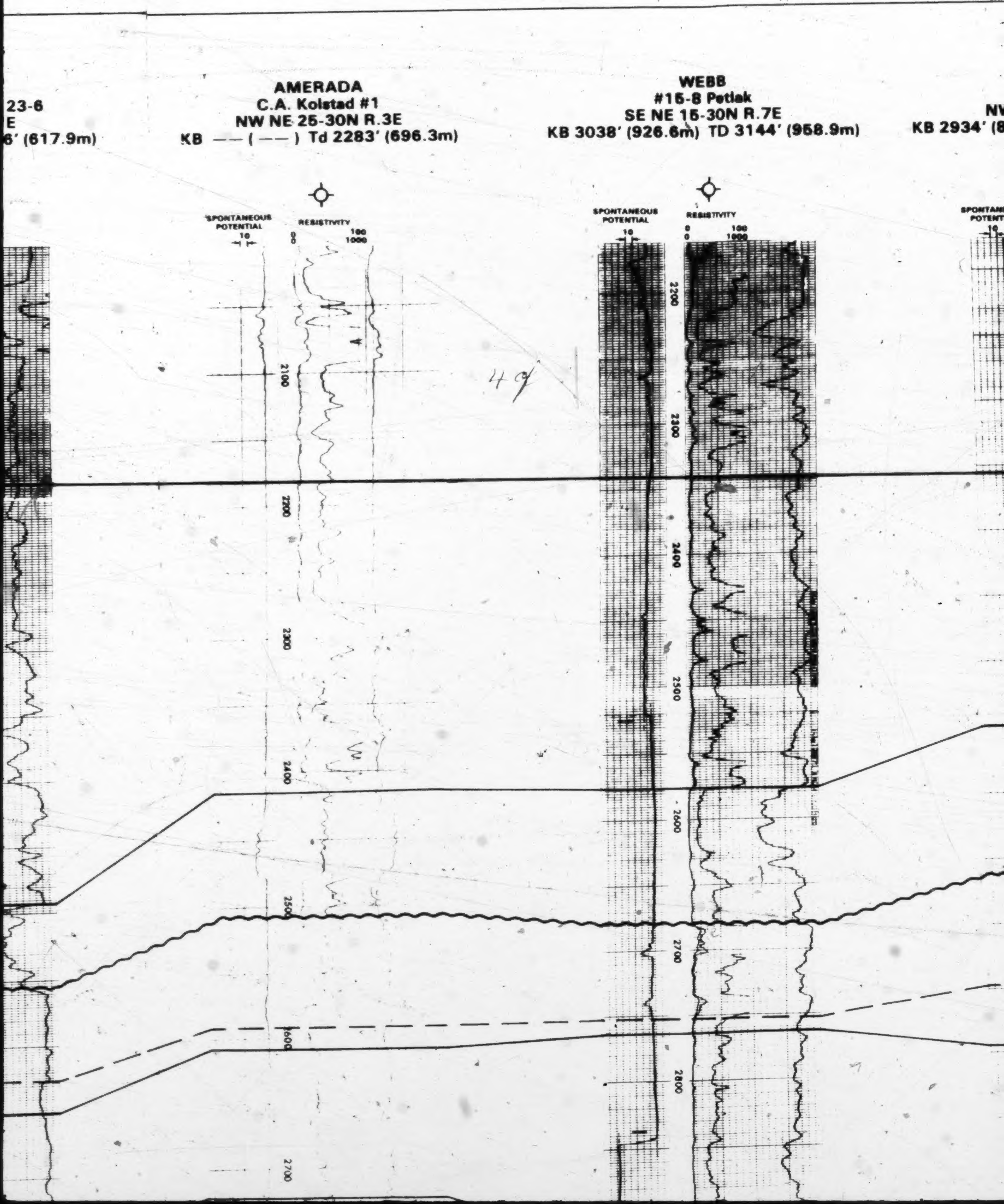

MONTALBAN
De Ruwe #1-A
NE NW 33-30N R.8W
KB 4138' (1262.1m) TD 5238' (1597.6m)
SPONTANEOUS POTENTIAL
10
RESISTIVITY
0
100
1000
4200
4300
4400
4500
4600
4700
4800
4900
WHELASS
Thistad #1
NW NW 16-30N R.7W
KB 4032' (1229.8m) TD 4578' (1396.3m)
SPONTANEOUS POTENTIAL
10
RESISTIVITY
0
100
1000
3600
3700
3800
3900
4000
4100
4200
430
1 of
LOWER CRETACEOUS
DATUM
800 feet below
BASE FISH
SCALES
BEAVER
MINES
GLADSTONE
CUT BANK

2 of

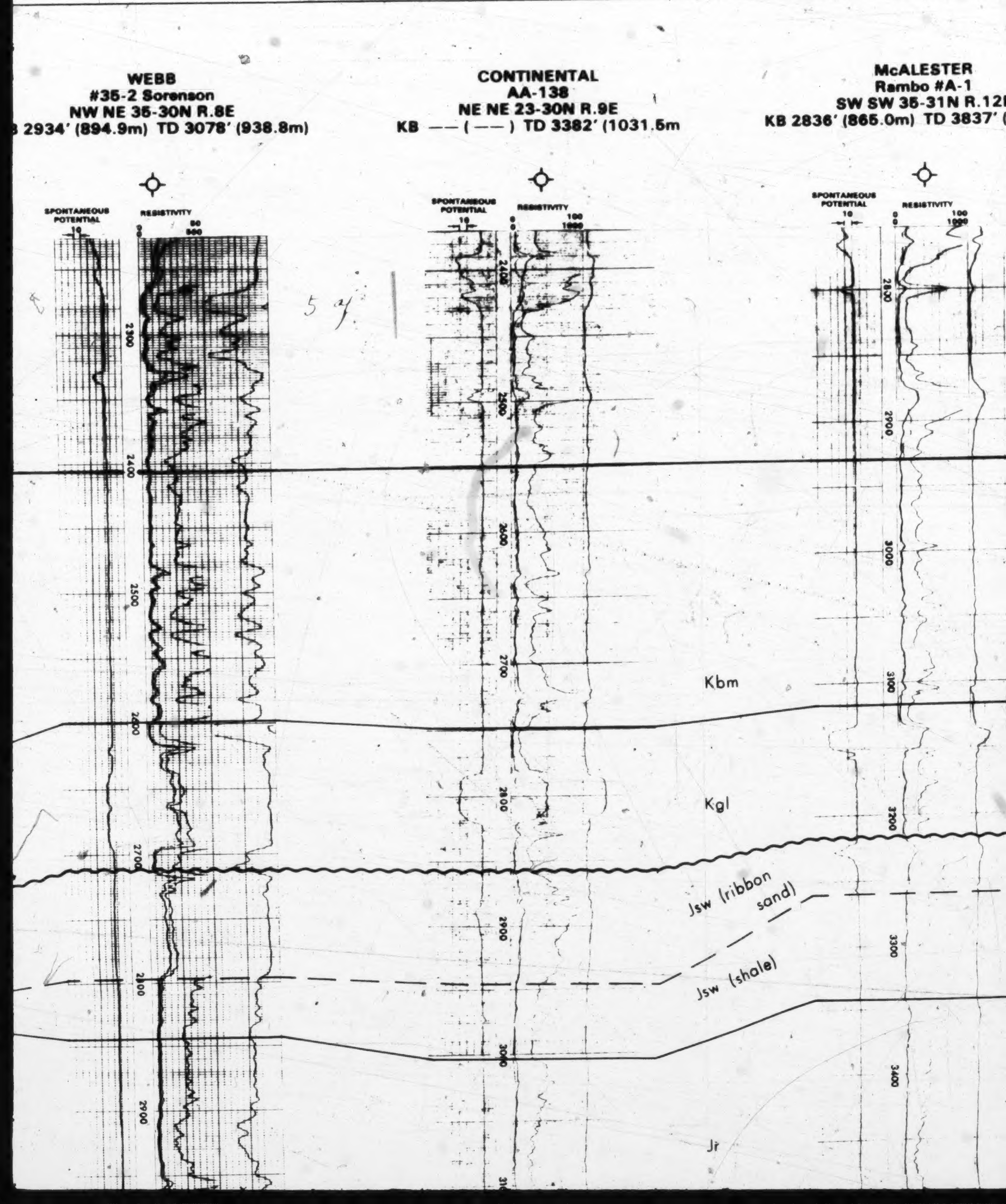


.3m)
ARNOLD
State 1-16
NE SE 16-30N R.5W
KB 3743′ (1141.6m) TD 3110′ (948.5m)
SPONTANEOUS POTENTIAL
10
RESISTIVITY
0
0
100
1000
2400
2500
2600
2700
2800
2900
3000
ENERGY RESERVES
#1-A-1 Van Auken
NW SE 14-30N R.4W
KB 3729′ (1137.3m) TD 2730′ (832.6m)
SPONTANEOUS POTENTIAL
10
RESISTIVITY
0
0
100
1000
2000
2100
2200
2300
2400
2500
2600
ACE-CA
Huyghe
NW SE 34
KB 3736′ (1139.5m
SPONTANEOUS POTENTIAL
20
1700
1800
1900
2000
2100
2200
2300
2400


ACE-CARDWELL
Huyghe #10C-34
NW SE 34-30N R.3W
' (1139.5m) TD 2530' (771.6m)
SPONTANEOUS POTENTIAL
20
RESISTIVITY
0
0
100
1000
1700
1800
1900
2000
2100
2200
2300
2400
MULE CREEK
Nierenberg #1
SW SW 25-30N R.1W
KB 3555' (1084.3m) TD 2273' (693.3m)
SPONTANEOUS POTENTIAL
10
RESISTIVITY
0
0
100
1000
1900
2000
WEBB
Marias Hereford Ranch 23-6
SE NW 23-30N R.1E
KB 3292' (1004.1m) TD 2026' (617.9
SPONTANEOUS POTENTIAL
10
RESISTIVITY
0
0
100
1000
1200
1300
1400
1500
1600
1700
1800
1900
Kbm
Kgl
Jsw (ribbon sand)
Jsw (shale)
3 af

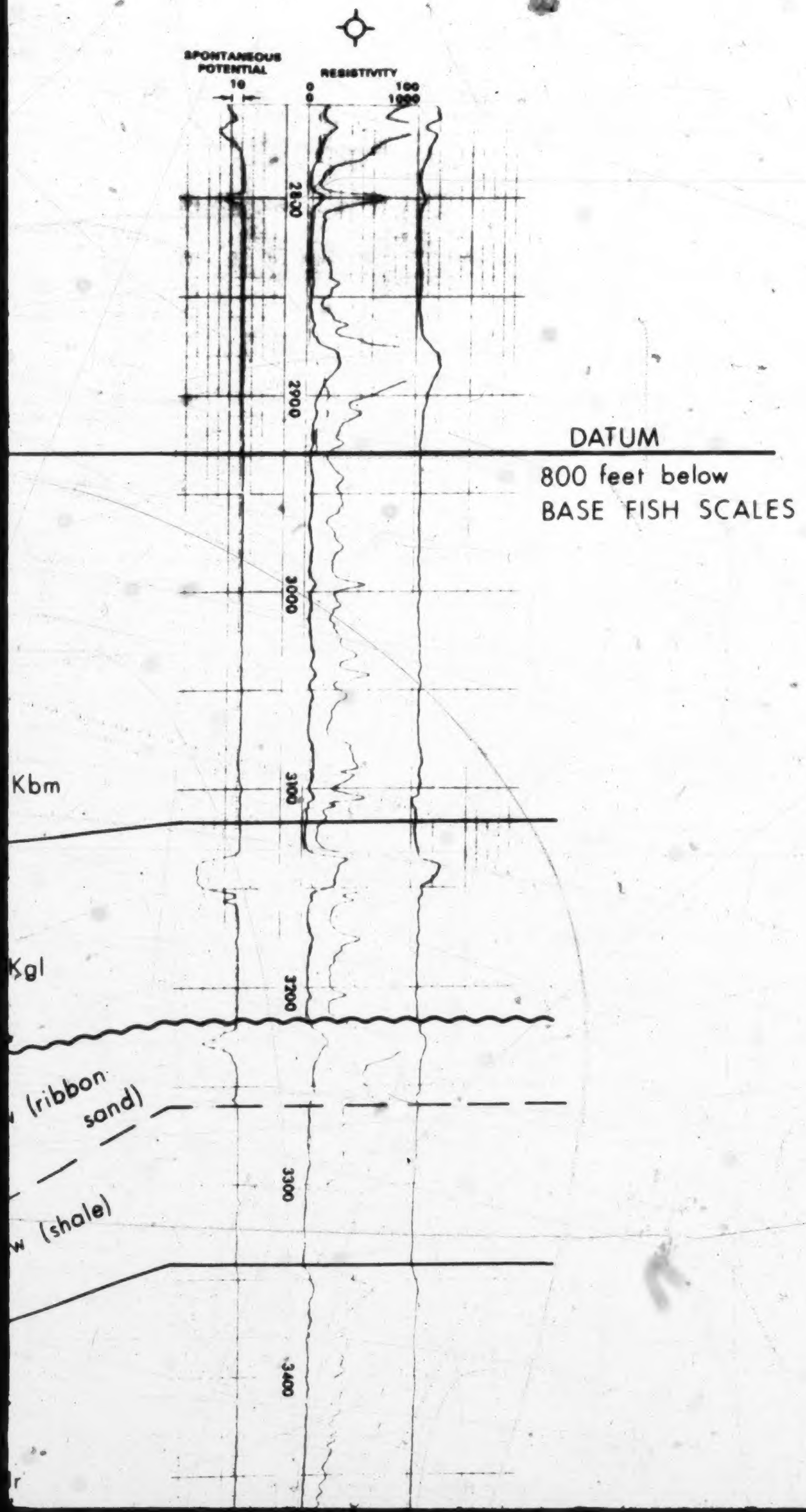

23-6
E
6' (617.9m)
AMERADA
C.A. Kolstad #1
NW NE 25-30N R.3E
KB —— (——) Td 2283' (696.3m)
SPONTANEOUS POTENTIAL
10
RESISTIVITY
0
100
1000
2100
2200
2300
2400
2500
2600
2700
WEBB
#15-8 Petlak
SE NE 15-30N R.7E
KB 3038' (926.6m) TD 3144' (958.9m)
SPONTANEOUS POTENTIAL
10
RESISTIVITY
0
0
100
1000
2200
2300
2400
2500
2600
2700
2800
NV
KB 2934' (8
SPONTANE
POTENT
10

49


WEBB
#35-2 Sorenson
NW NE 35-30N R.8E
2934' (894.9m) TD 3078' (938.8m)
CONTINENTAL
AA-138
NE NE 23-30N R.9E
KB —— (——) TD 3382' (1031.5m
McALESTER
Rambo #A-1
SW SW 35-31N R.12
KB 2836' (865.0m) TD 3837' (
SPONTANEOUS POTENTIAL
10
RESISTIVITY
0
50
500
100
1000
2300
2400
2500
2600
2700
2800
2900
3000
3100
3200
3300
3400
Kbm
Kgl
Jsw (ribbon sand)
Jsw (shale)
Jr
5 aj

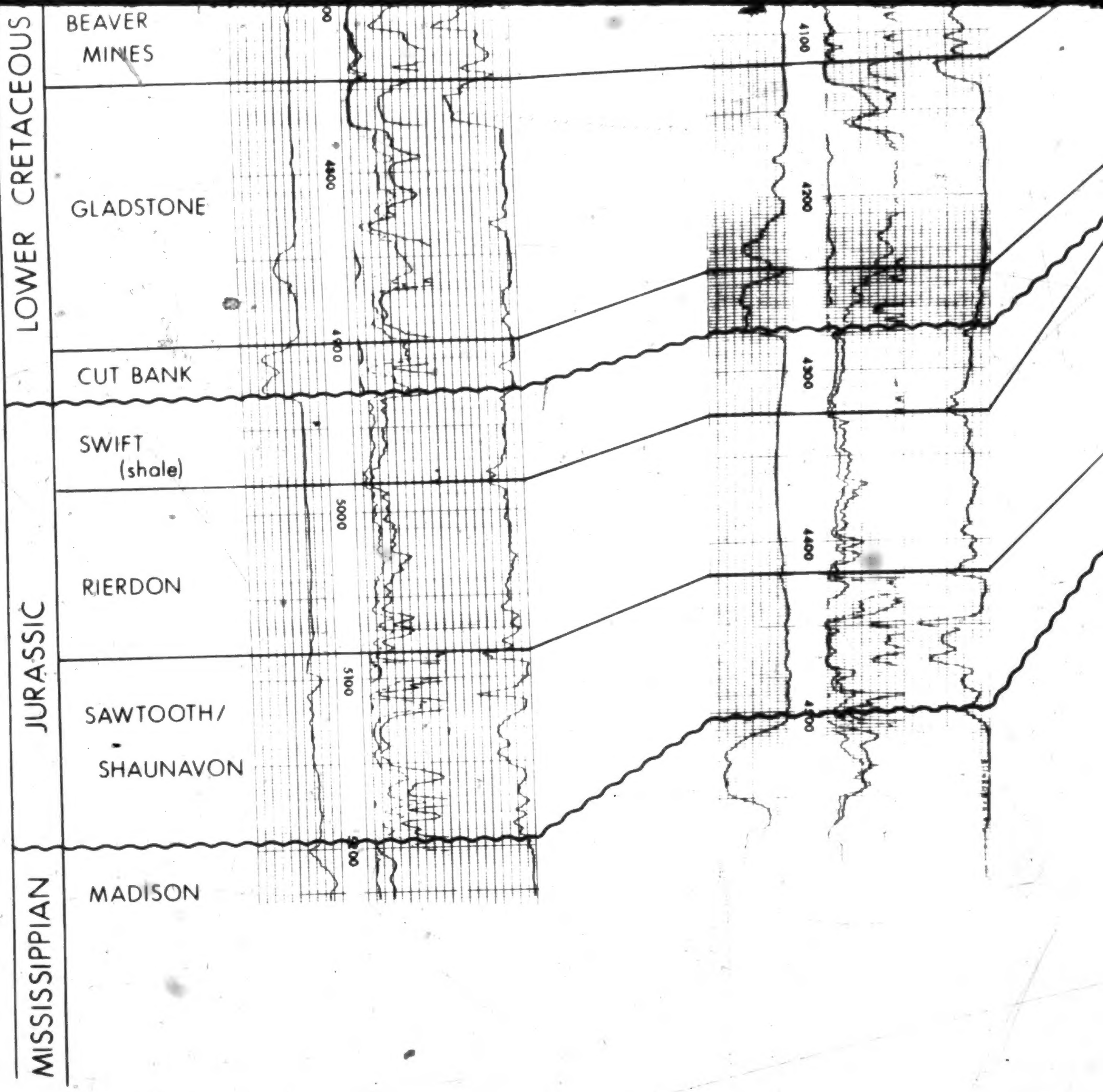
E3

McALESTER
Rambo #A-1
SW SW 35-31N R.12E
KB 2836' (865.0m) TD 3837' (1170.3m)

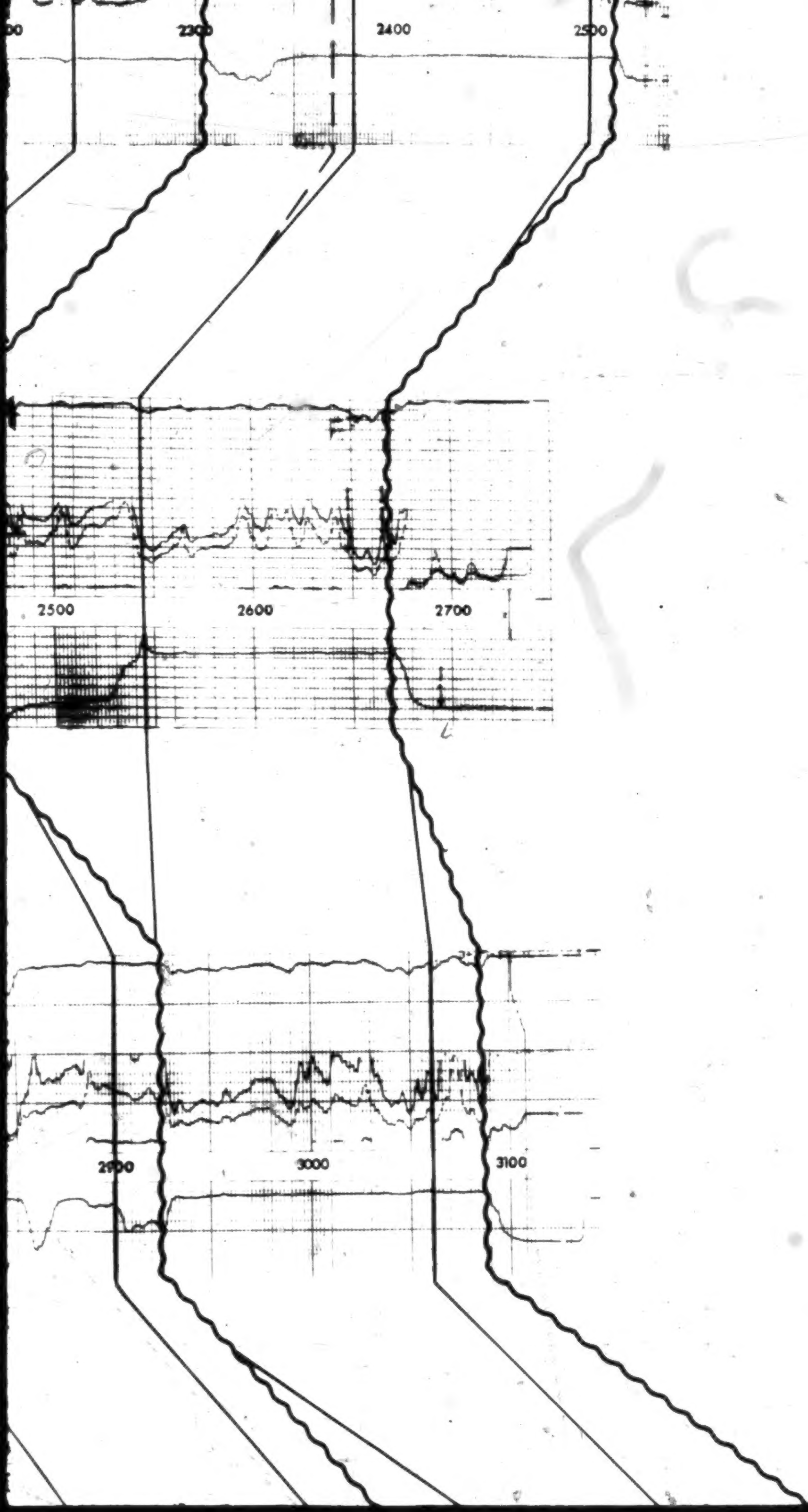


SPONTANEOUS POTENTIAL
10
RESISTIVITY
0
0
100
1000
2800
2900
3000
3100
3200
3300
3400
DATUM
800 feet below
BASE FISH SCALES
Kbm
Kgl
(ribbon sand)
(shale)

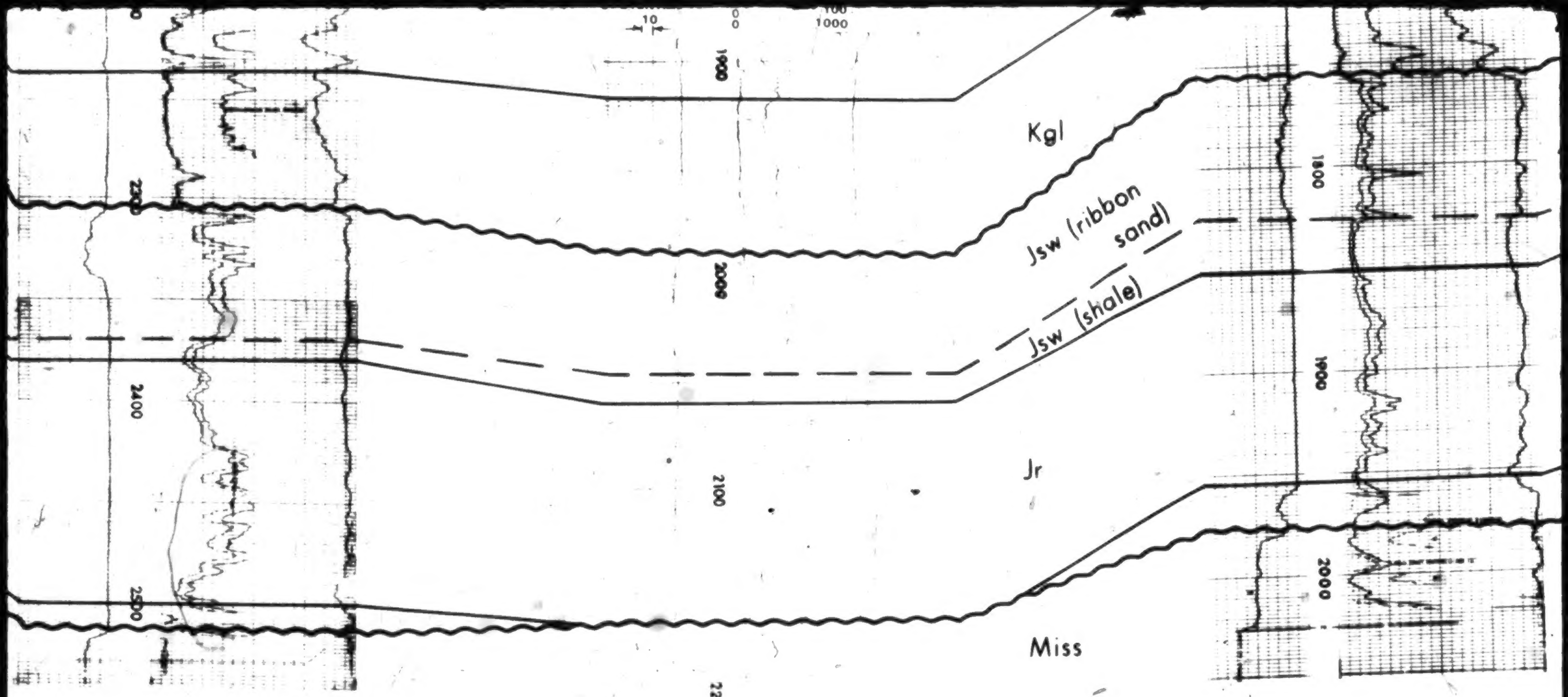
6 a/


LOWER CRETACEOUS
BEAVER MINES
GLADSTONE
CUT BANK
JURASSIC
SWIFT (shale)
RIERDON
SAWTOOTH/
SHAUNAVON
MISSISSIPPIAN
MADISON
4800
4900
5000
5100
5200
4100
4200
4300
4400
4500

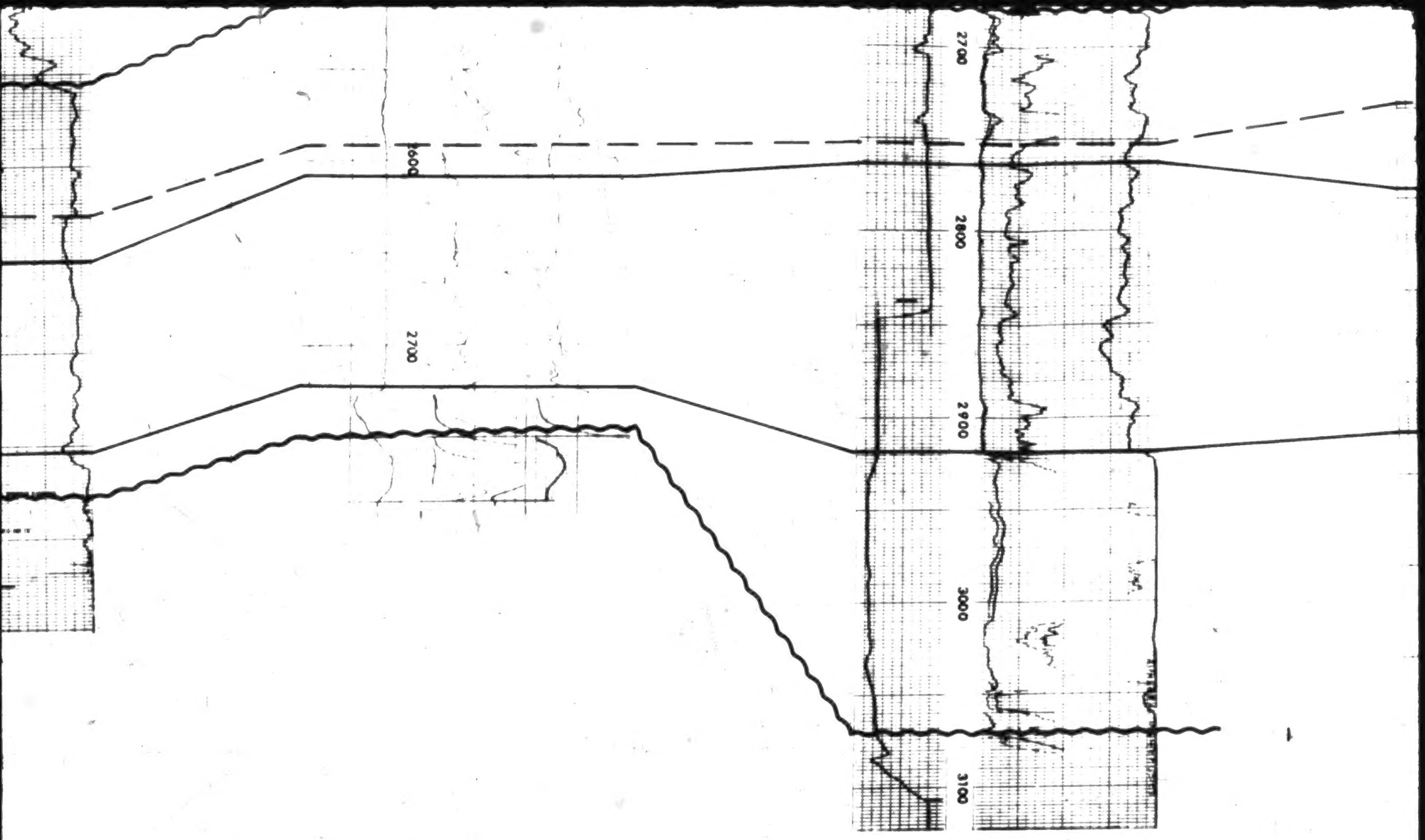
4 of


2300
2400
2500
2500
2600
2700
2900
3000
3100

8 of

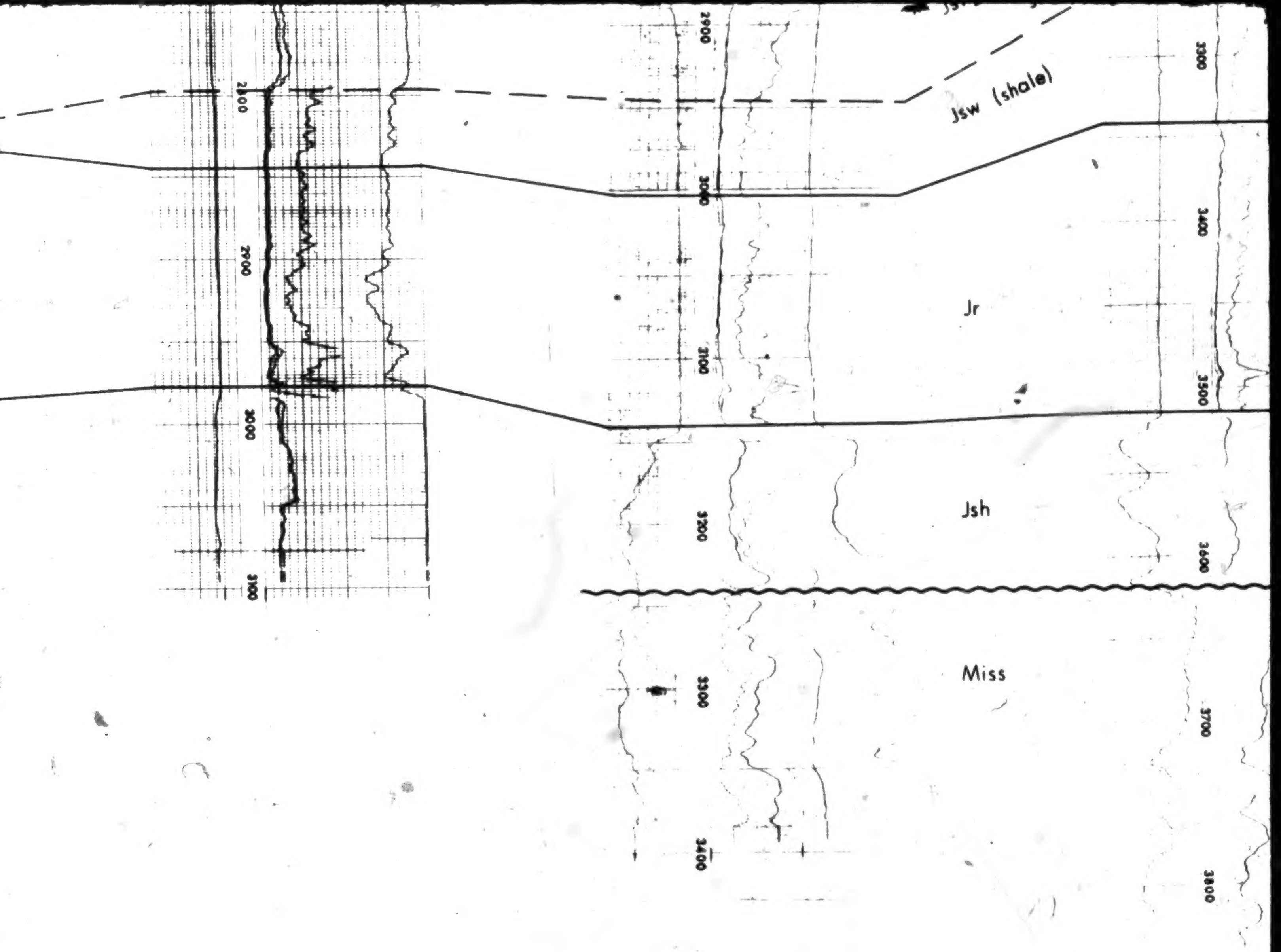

10
0
0
100
1000
1900
2000
2100
2200
2300
2400
2500
1800
1900
2000
Kgl
Jsw (ribbon sand)
Jsw (shale)
Jr
Miss

9 of

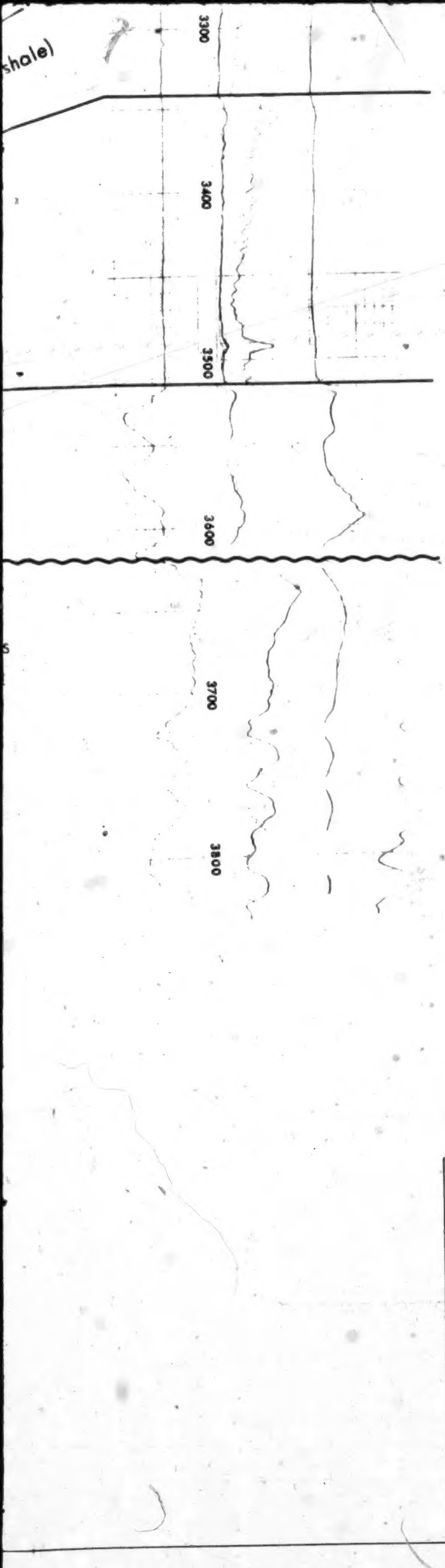


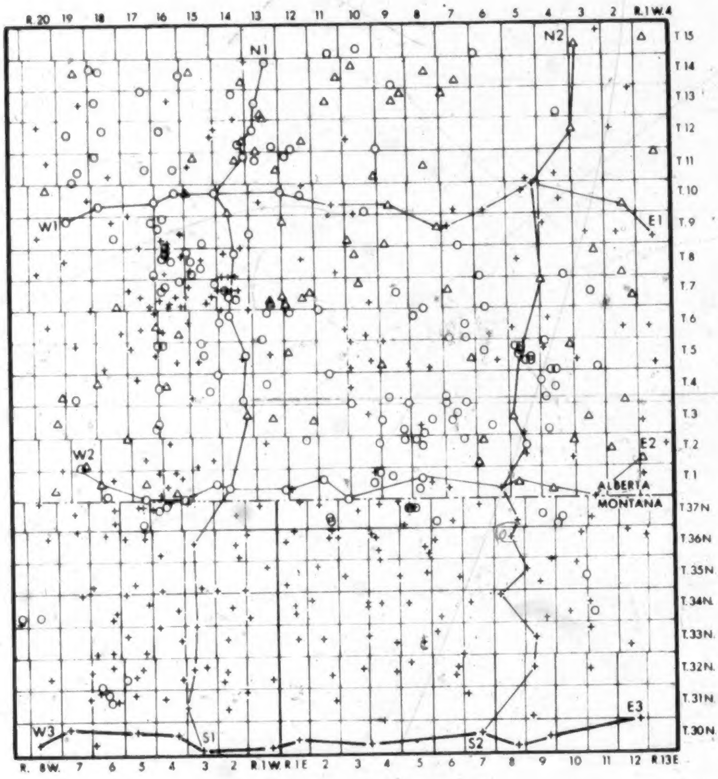
2700
2800
2900
3000
3100
600
2700

10 of


Jsw (shale)
Jr
Jsh
Miss

11 of


shale)
3300
3400
3500
3600
3700
3800


R.20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 R.1W.4
T.15
T.14
T.13
T.12
T.11
T.10
T.9
T.8
T.7
T.6
T.5
T.4
T.3
T.2
T.1
T.37N.
T.36N.
T.35N.
T.34N.
T.33N.
T.32N.
T.31N.
T.30N.
R. 8W. 7 6 5 4 3 2 R.1W R.1E 2 3 4 5 6 7 8 9 10 11 12 R.13E.
N1
N2
W1
E1
W2
E2
W3
E3
S1
S2
ALBERTA
MONTANA

CROSS SECTION LOCATION MAP
SOUTHEASTERN ALBERTA-NORTHERN MONTANA

0 5 10 15 20 25 30
MILES (Approx.)

FIGURE 11

STRATIGRAPHIC CROSS SECTION
W3-E3

DATUM: 800 feet below Base of Fish Scales

B. Hayes
University of Alberta
1981

VERTICAL SCALE: 1" = 80 ft.

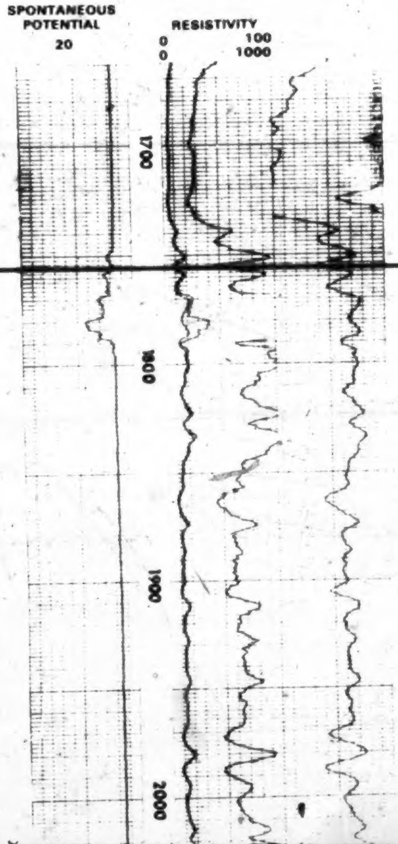
12 of 12

S1

ACE-CARDWELL
Huyghe #10C-34
NW SE-34-30N R.3W
KB 3736' (1[illegible]39.5m) TD 2535' (773.2m)

DOME
Denzer #1
NE SE-19-31N R.3W
KB 3453' (1053.2m) TD 2463' (751.2m)

1 of



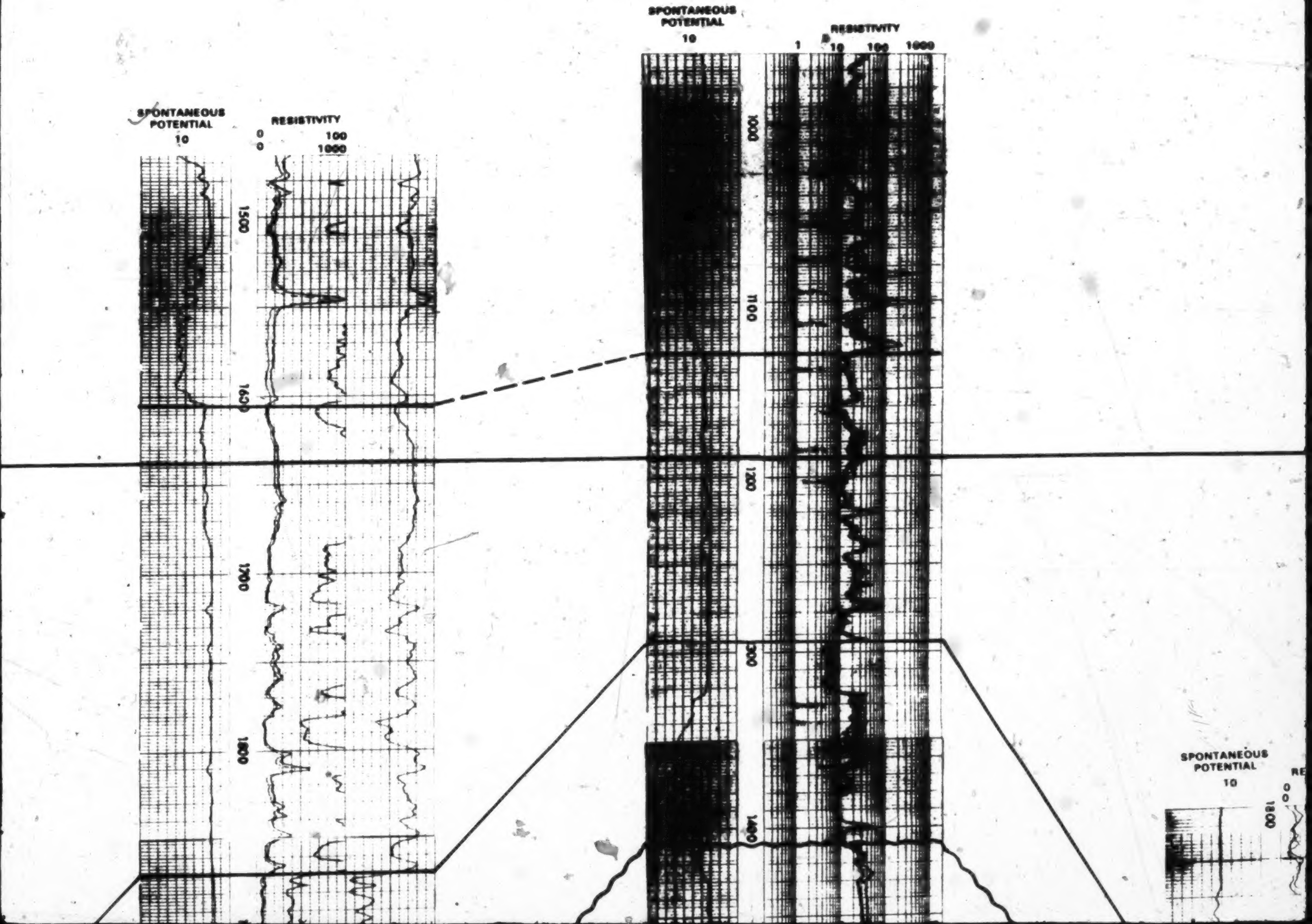
DATUM: 700' below Base of Fish Scales

DUNOCO
State #1
NW NW-16-32N R.3W
KB 3547' (1081.8m) TD 2221' (677.4m)

ENERGY RESERVES
#1 Flesch
SW SE-33-34N R.3W
KB 3327' (1014.7m) TD 1677' (511.5m)

PHIL
Rattlesna
SE NE-17-
KB 3568' (1088.2m)

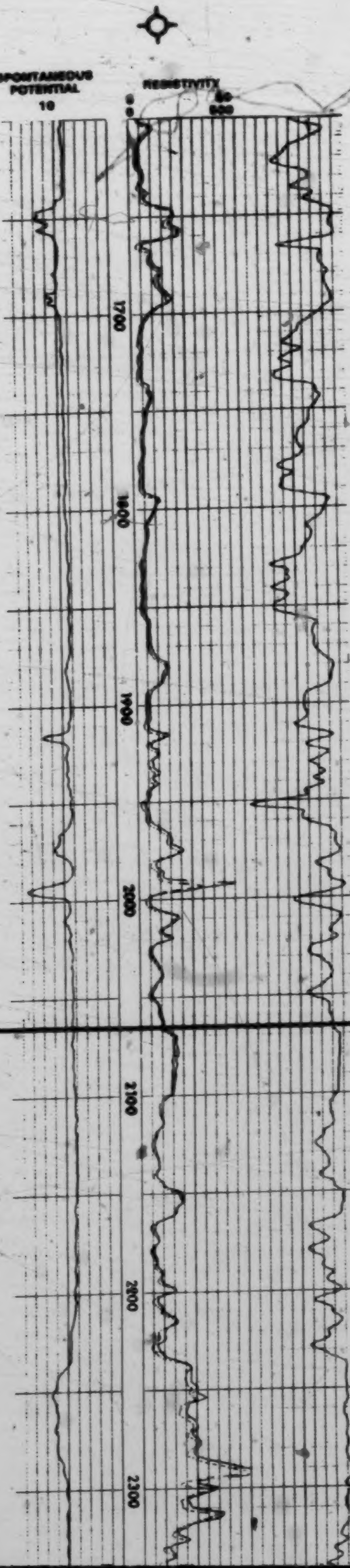
2 of 1



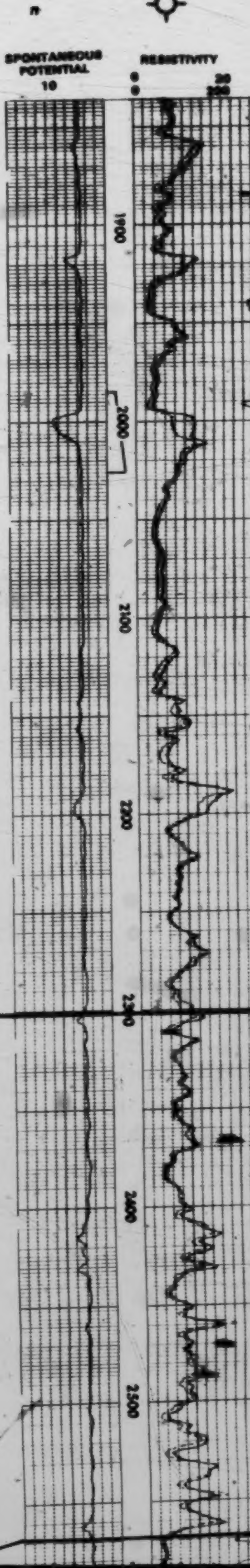
PHILLIPS
Rattlesnake Coulee
SE NE-17-36N R.3W
568' (1088.2m) TD 2240' (683.2m)

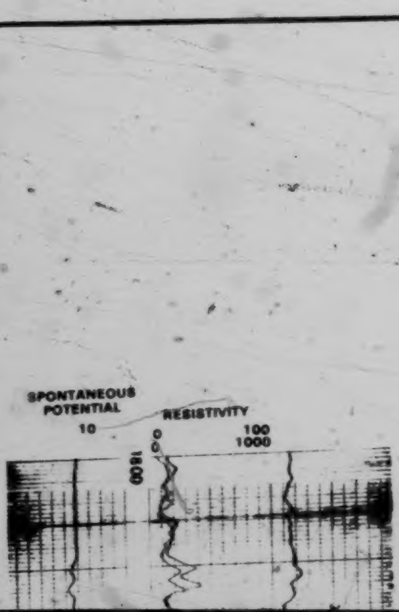
UNION
Coutts 7-18
7-18-1-14W4
KB 2977' (913.5m) TD 3124' (959.8m)

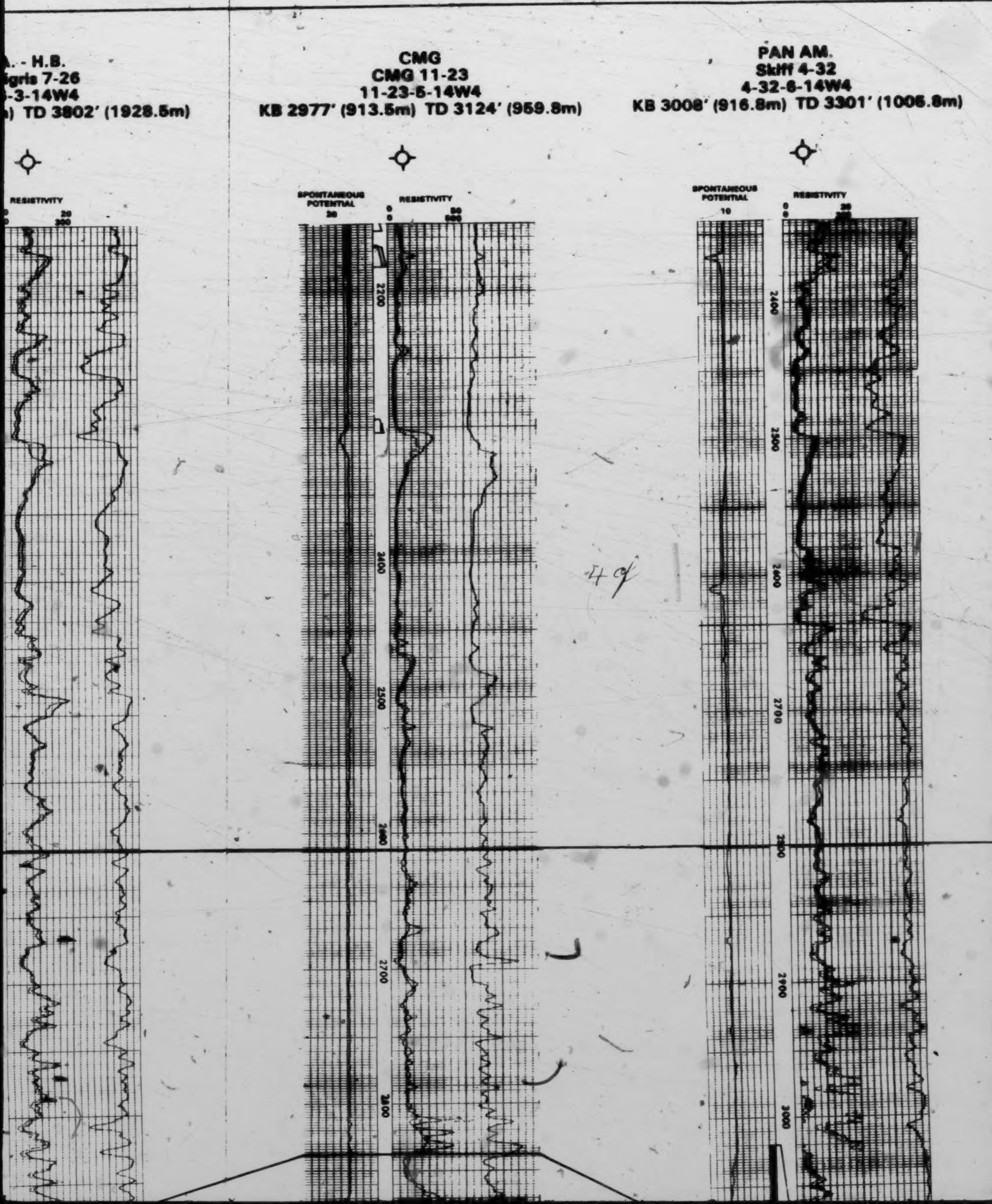
B.A. - H.B.
Verdigris 7-26
7-26-3-14W4
KB 3082' (939.4m) TD 380



3 of

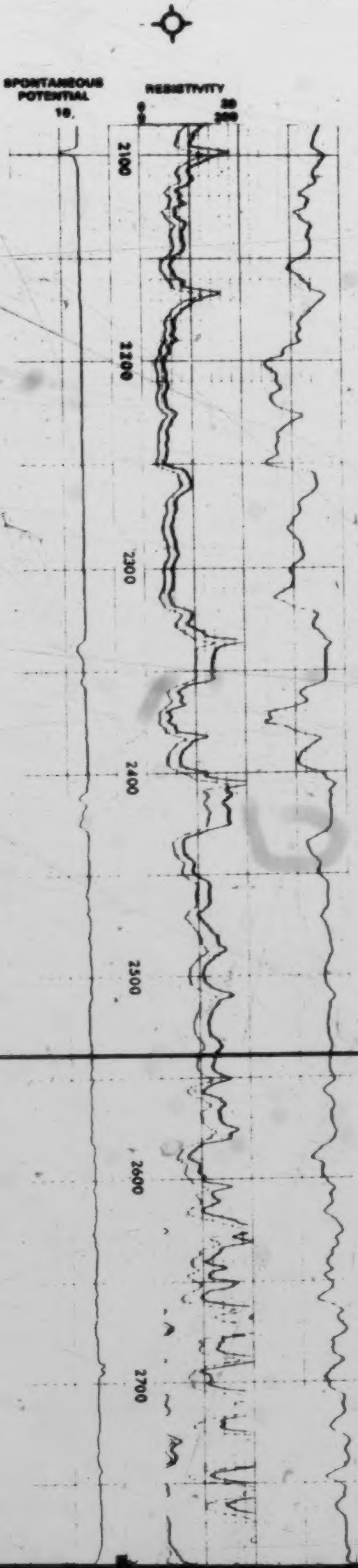





A. - H.B.
igris 7-26
-3-14W4
) TD 3802' (1928.5m)
RESISTIVITY
20
200
CMG
CMG 11-23
11-23-5-14W4
KB 2977' (913.5m) TD 3124' (959.8m)
SPONTANEOUS POTENTIAL
20
RESISTIVITY
0
0
50
500
2200
2300
2400
2500
2600
2700
2800
PAN AM.
Skiff 4-32
4-32-6-14W4
KB 3008' (916.8m) TD 3301' (1006.8m)
SPONTANEOUS POTENTIAL
10
RESISTIVITY
0
20
200
2400
2500
2600
2700
2800
2900
3000
4 of

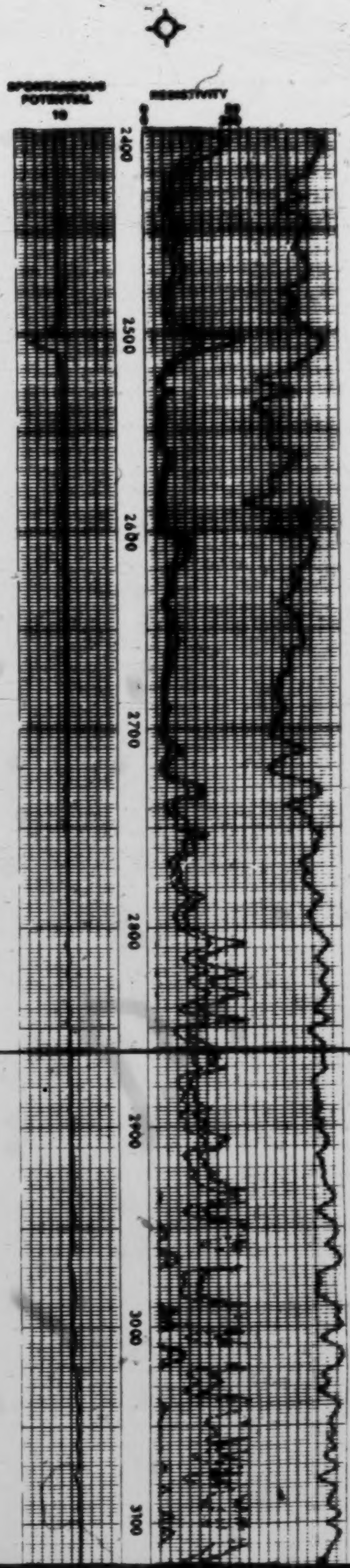
3m)

BRETT
Chin Coulee 15-17
15-17-7-14W4
KB 2686' (818.7m) TD 2950' (899.2m)

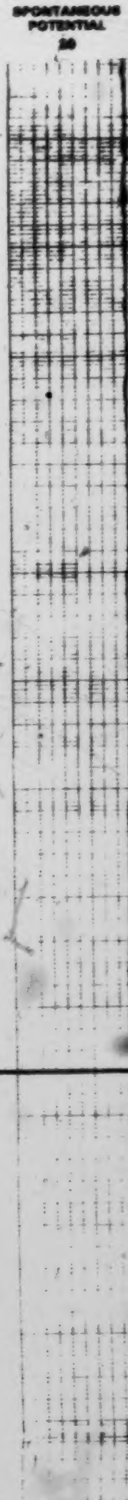


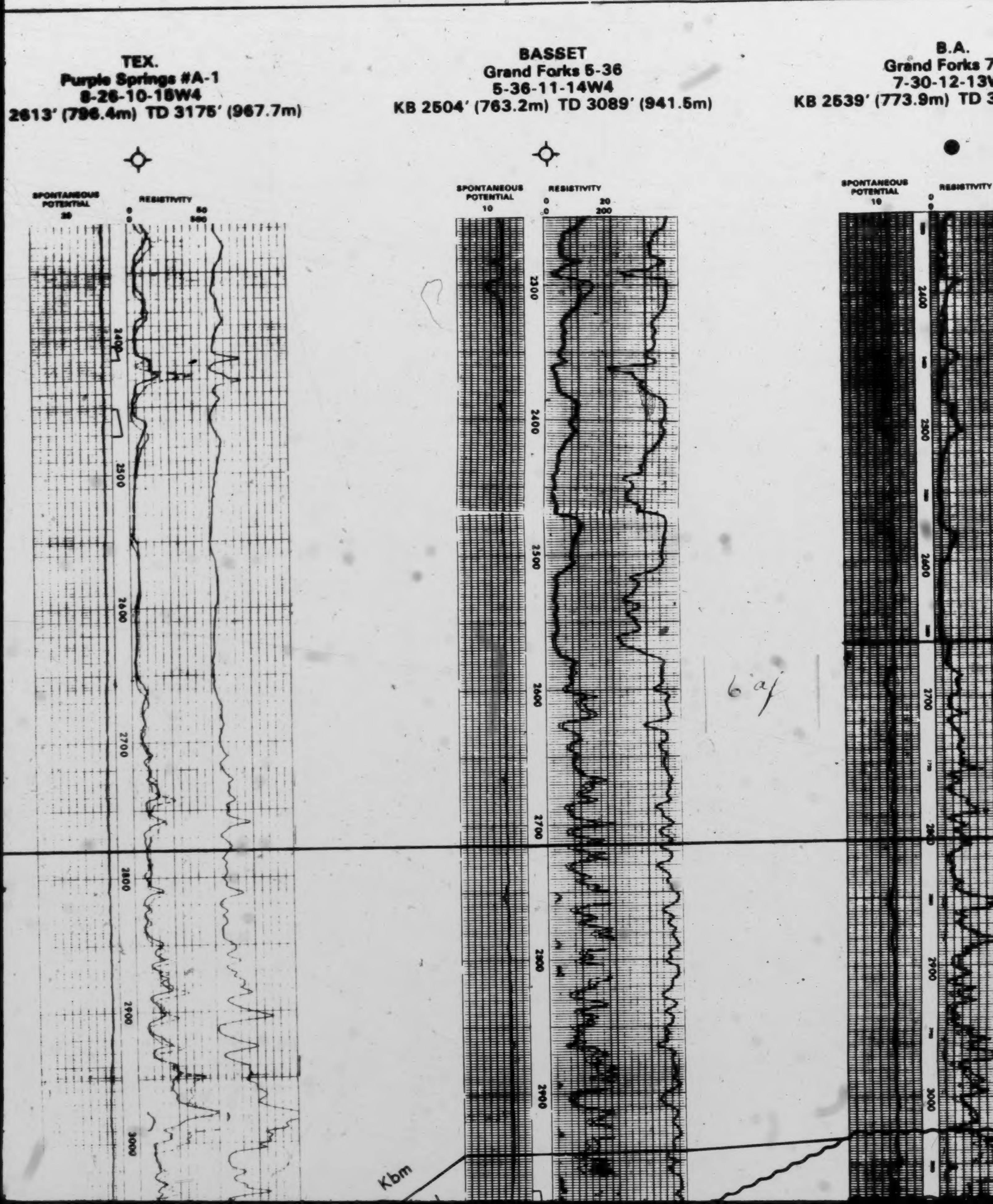
5 of

SUN
Chinco 7-28
7-28-8-14W5
KB 2852' (869.3m) TD 3250' (1004.6m)

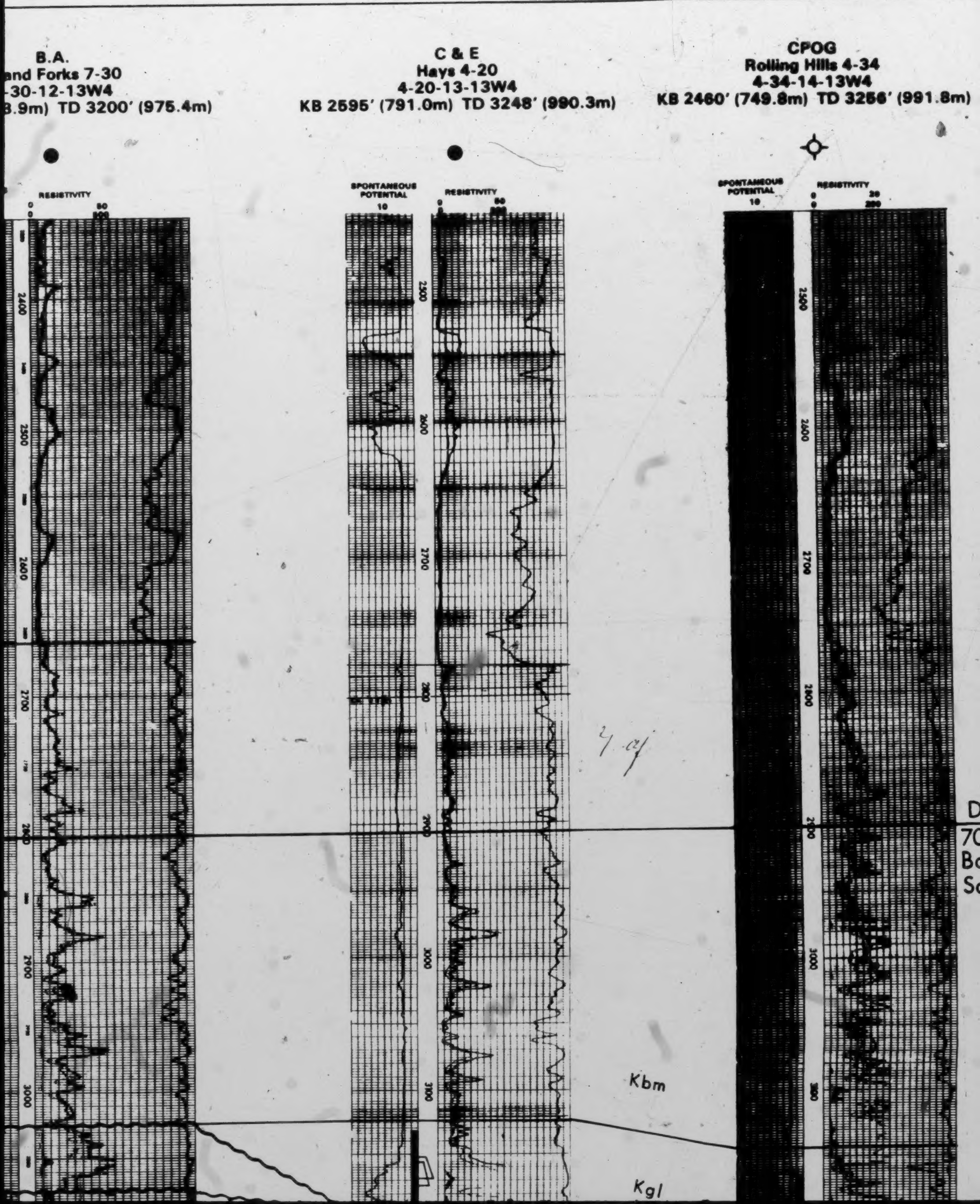


Purpl
8-2
KB 2613' (796.




TEX.
Purple Springs #A-1
8-26-10-15W4
2613' (796.4m) TD 3175' (967.7m)
SPONTANEOUS POTENTIAL
20
RESISTIVITY
0
0
50
500
2400
2500
2600
2700
2800
2900
3000
BASSET
Grand Forks 5-36
5-36-11-14W4
KB 2504' (763.2m) TD 3089' (941.5m)
SPONTANEOUS POTENTIAL
10
RESISTIVITY
0
0
20
200
2300
2400
2500
2600
2700
2800
2900
B.A.
Grand Forks 7
7-30-12-13V
KB 2539' (773.9m) TD 3
SPONTANEOUS POTENTIAL
10
RESISTIVITY
0
0
2400
2500
2600
2700
2800
2900
3000
Kbm

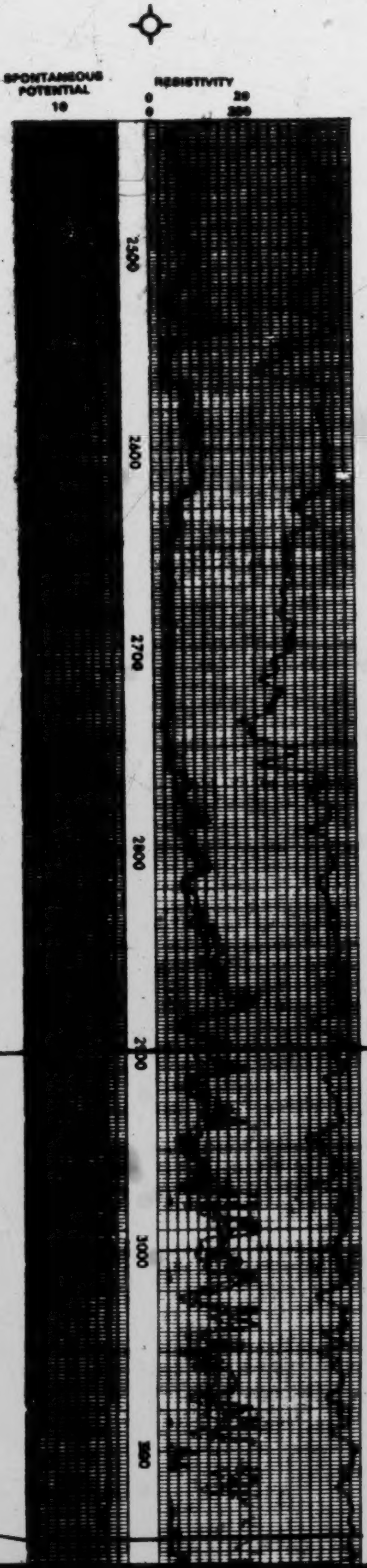
6 af


B.A.
and Forks 7-30
-30-12-13W4
3.9m) TD 3200' (975.4m)
RESISTIVITY
0 50
0 500
2400
2500
2600
2700
2800
2900
3000
C & E
Hays 4-20
4-20-13-13W4
KB 2595' (791.0m) TD 3248' (990.3m)
SPONTANEOUS POTENTIAL
10
RESISTIVITY
0 50
0 500
2500
2600
2700
2800
2900
3000
3100
CPOG
Rolling Hills 4-34
4-34-14-13W4
KB 2460' (749.8m) TD 3256' (991.8m)
SPONTANEOUS POTENTIAL
10
RESISTIVITY
0 20
0 200
2500
2600
2700
2800
2900
3000
3100
Kbm
Kgl
D
70
Bo
So

4 of

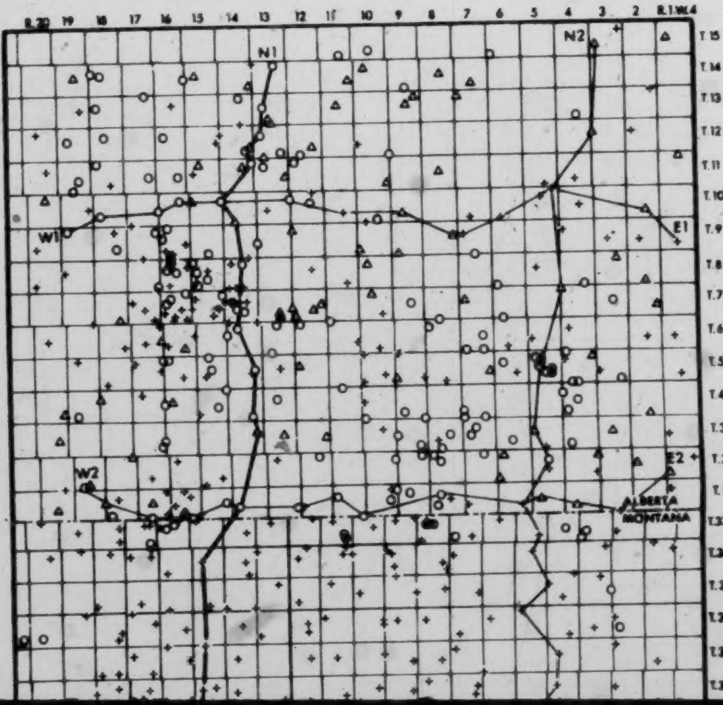
N1

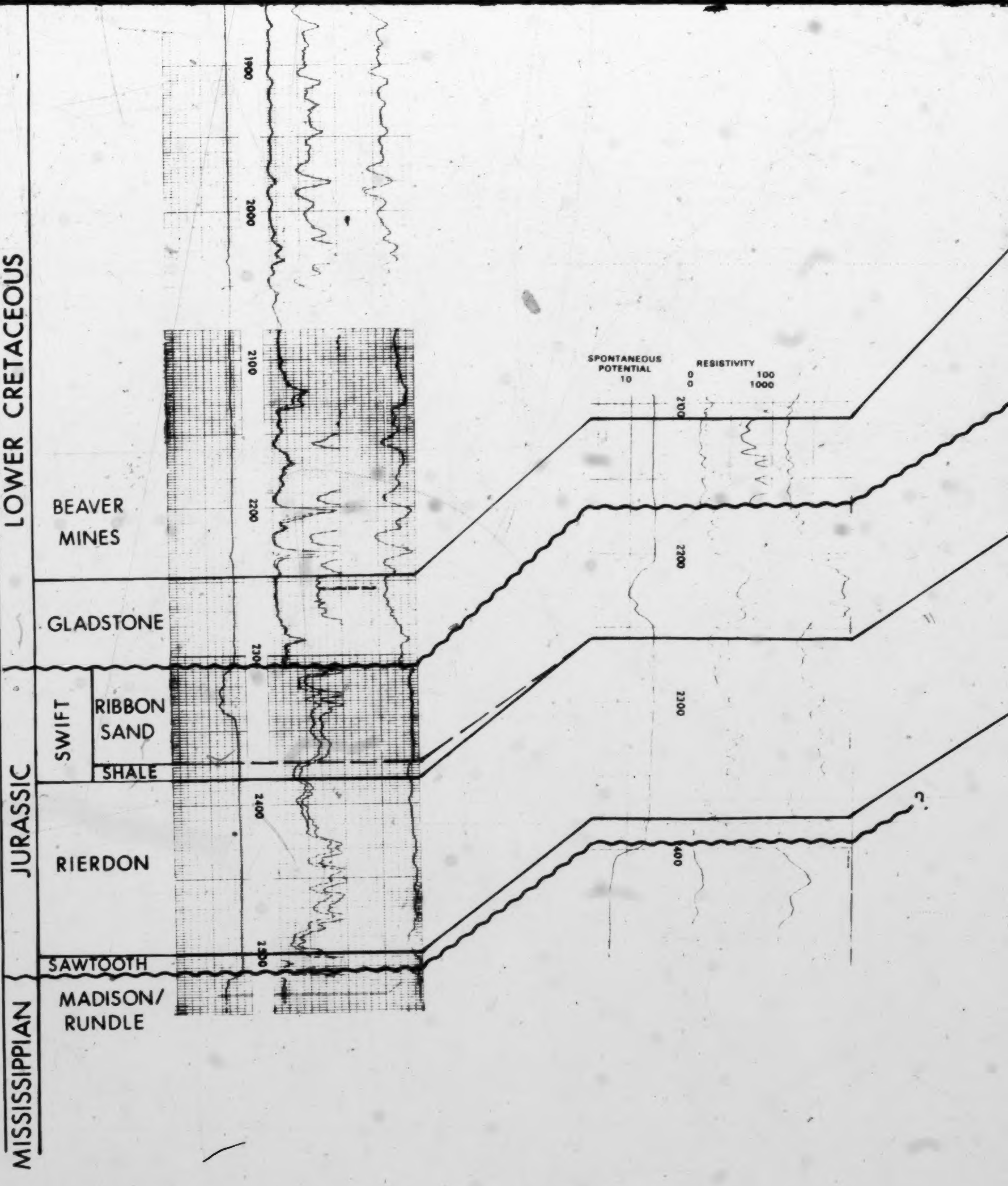
CPOG
Rolling Hills 4-34
4-34-14-13W4
KB 2460' (749.8m) TD 3256' (991.8m)



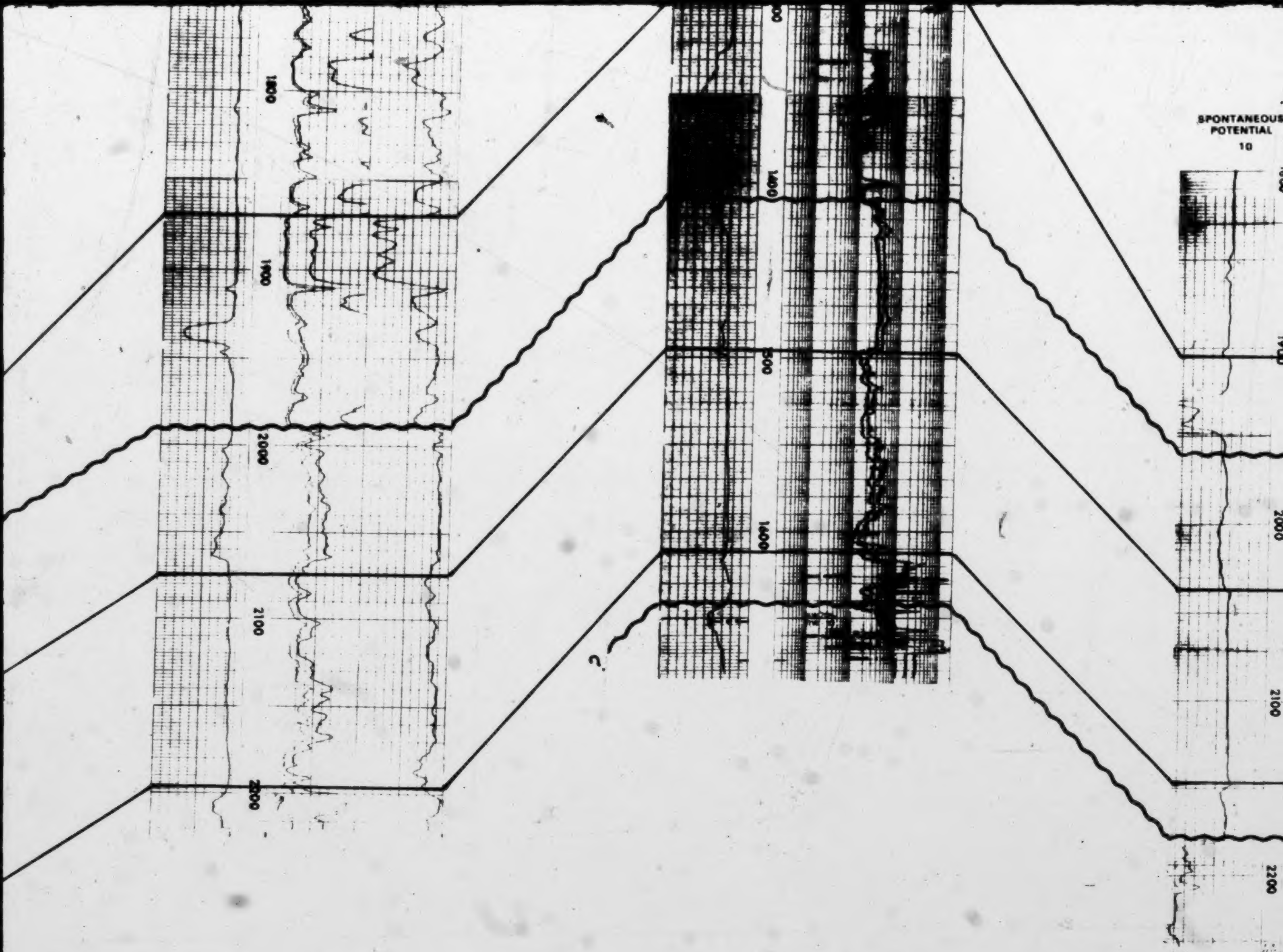
DATUM:
700' below
Base of Fish
Scales.

8 of

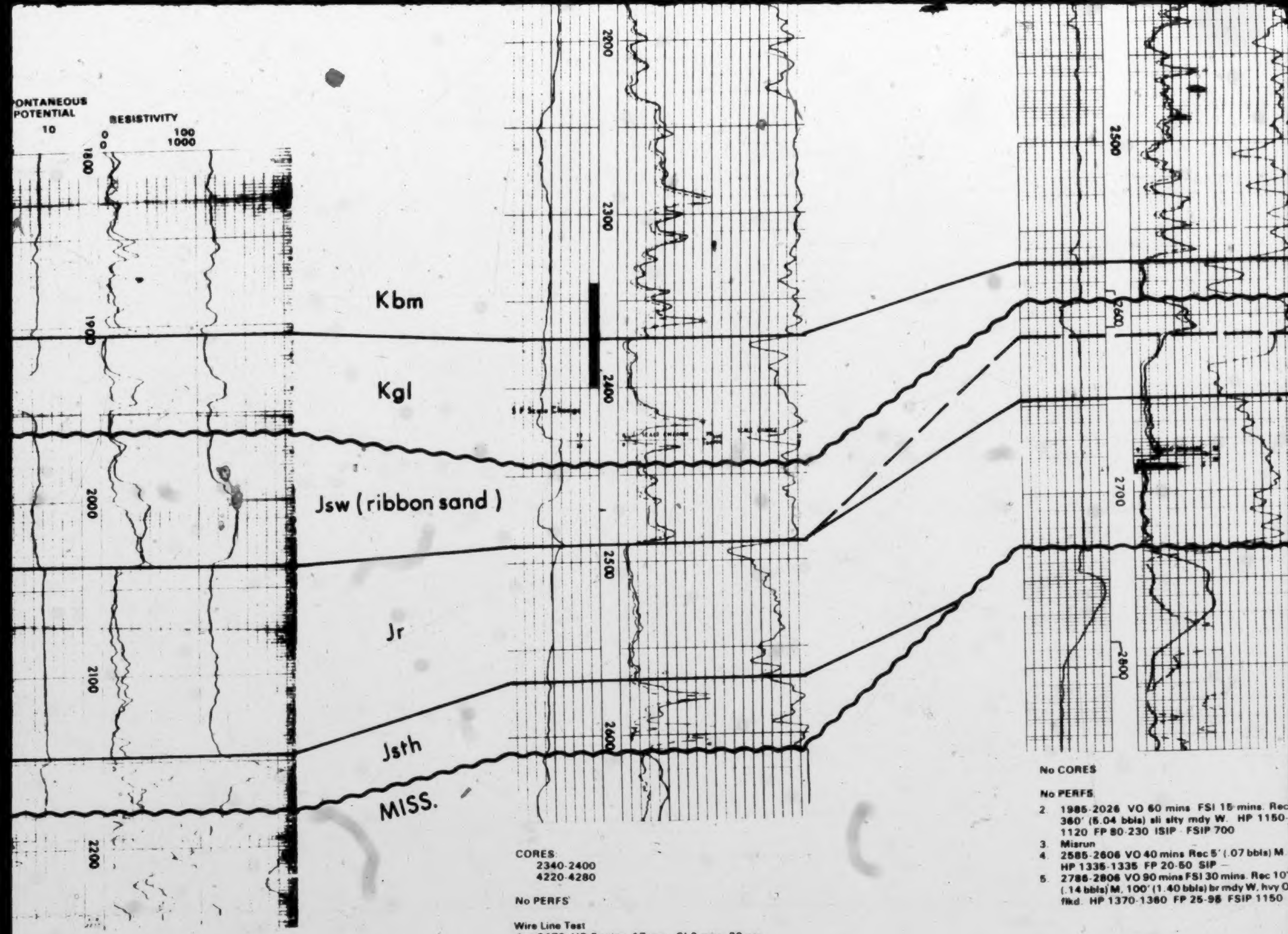

R.20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
R.1.W.4
T.15
T.14
T.13
T.12
T.11
T.10
T.9
T.8
T.7
T.6
T.5
T.4
T.3
T.2
T.1
T.37N.
T.36N.
T.35N.
T.34N.
T.33N.
T.32N.
N1
N2
W1
W2
E1
E2
ALBERTA
MONTANA


LOWER CRETACEOUS
JURASSIC
MISSISSIPPIAN
BEAVER MINES
GLADSTONE
SWIFT
RIBBON SAND
SHALE
RIERDON
SAWTOOTH
MADISON/ RUNDLE
1900
2000
2100
2200
230
2400
2500
SPONTANEOUS POTENTIAL
10
RESISTIVITY
0
0
100
1000
200
2200
2300
400
?

9 of


SPONTANEOUS POTENTIAL
10
1800
1900
2000
2100
2200
1400
1500
1600
?
2000
2100
2200

10 of



CORES:
2340-2400
4220-4280

No PERFS

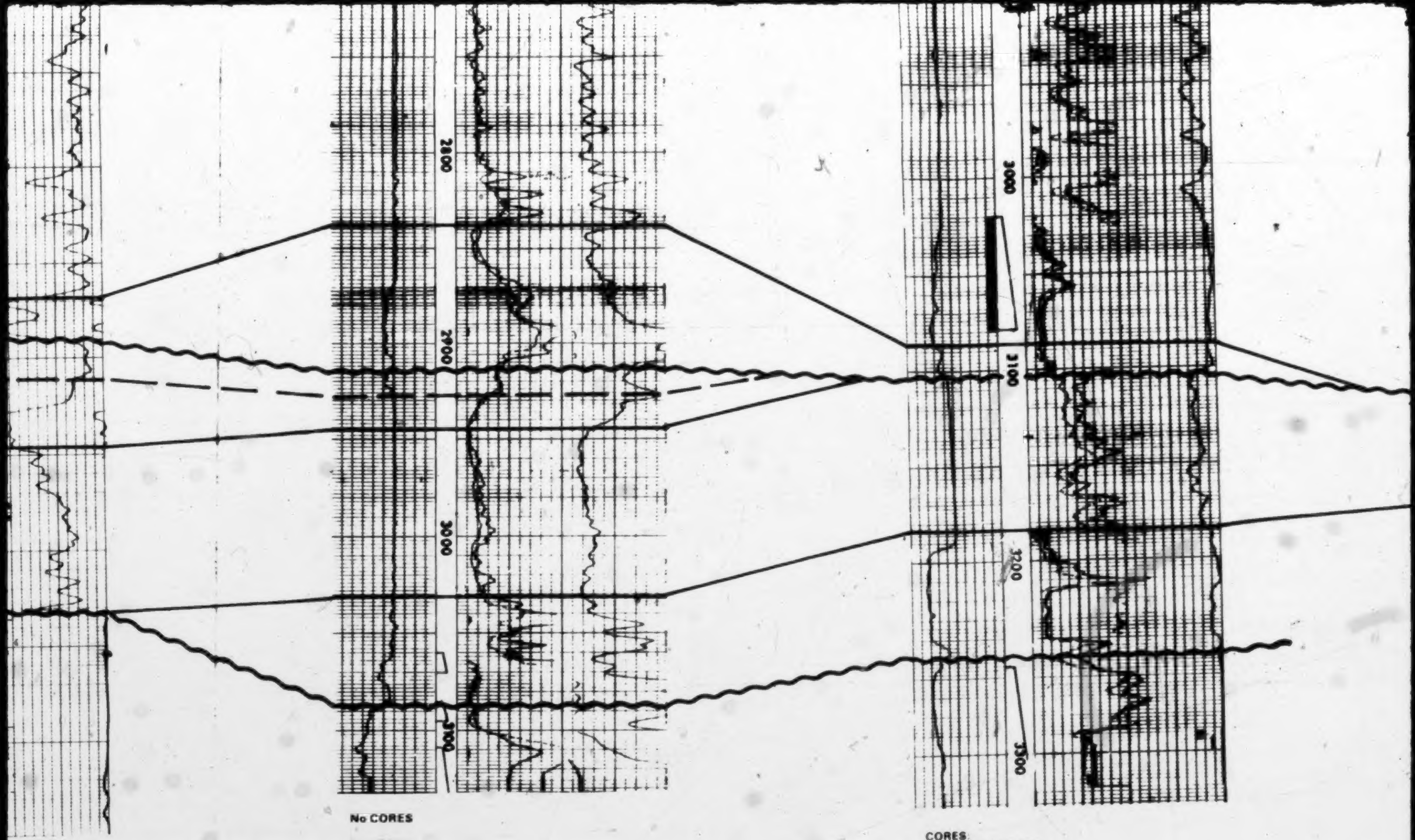
Wire Line Test
1. 2470 VO 5 mins 17 sec. SI 3 mins 20 sec. Rec 20,000 c.c. fr W, 0.45 cu ft G. Res. 1.8 @ 60° 29% of mixture W. FP NR HP 1350 SIP 780

No CORES

No PERFS

2. 1985-2026 VO 60 mins FSI 15 mins. Rec 360' (5.04 bbls) sli slty mdy W. HP 1150-1120 FP 80-230 ISIP - FSIP 700
3. Misrun
4. 2585-2606 VO 40 mins Rec 5' (.07 bbls) M. HP 1335-1335 FP 20-50 SIP —
5. 2786-2806 VO 90 mins FSI 30 mins. Rec 10' (.14 bbls) M, 100' (1.40 bbls) br mdy W, hvy O flkd. HP 1370-1360 FP 25-95 FSIP 1150

11 of



15 mins. Rec
W. HP 1150-
700

' (.07 bbls) M.

mins. Rec 10'
mdy W, hvy O
FSIP 1150

No CORES

No PERFS

4. 2166-82 VO 30 mins Shut in 10 mins. GIP. Rec 1190' W. FP 500 SIP 775
5. 2294-2304 VO 30 mins Shut in 10 mins. GIP sli stdy blow. FP 0 SIP 875
6. 2240-2455 VO 30 mins. Shut in 10 mins. GIP & faint blow. Rec 5' M. FP 0 SIP 0
7. 3060-70 VO 45 mins. GIP VFB dying after 10 mins. Rec 2' M
8. 3085-95 VO 1 hr. Shut in 10 mins. GIP. small blow, dec. sli Rec 265' sul. W. FP 0 SIP 1260
9. 3109-49 VO 30 mins Shut in 15 mins GIP very stdy blow (non inflammable)
10. 2067-2085 Misrun
11. 2055-80 Misrun
12. 2050-80 VO 30 mins (no shut in). GIP & small stdy blow. Rec 430' sli GC & sli SW
13. 2108-2133 VO 30 mins Shut in 10 mins. Rec 340' W.
14. 2167-82 VO 30 mins. Rec 1160' SW

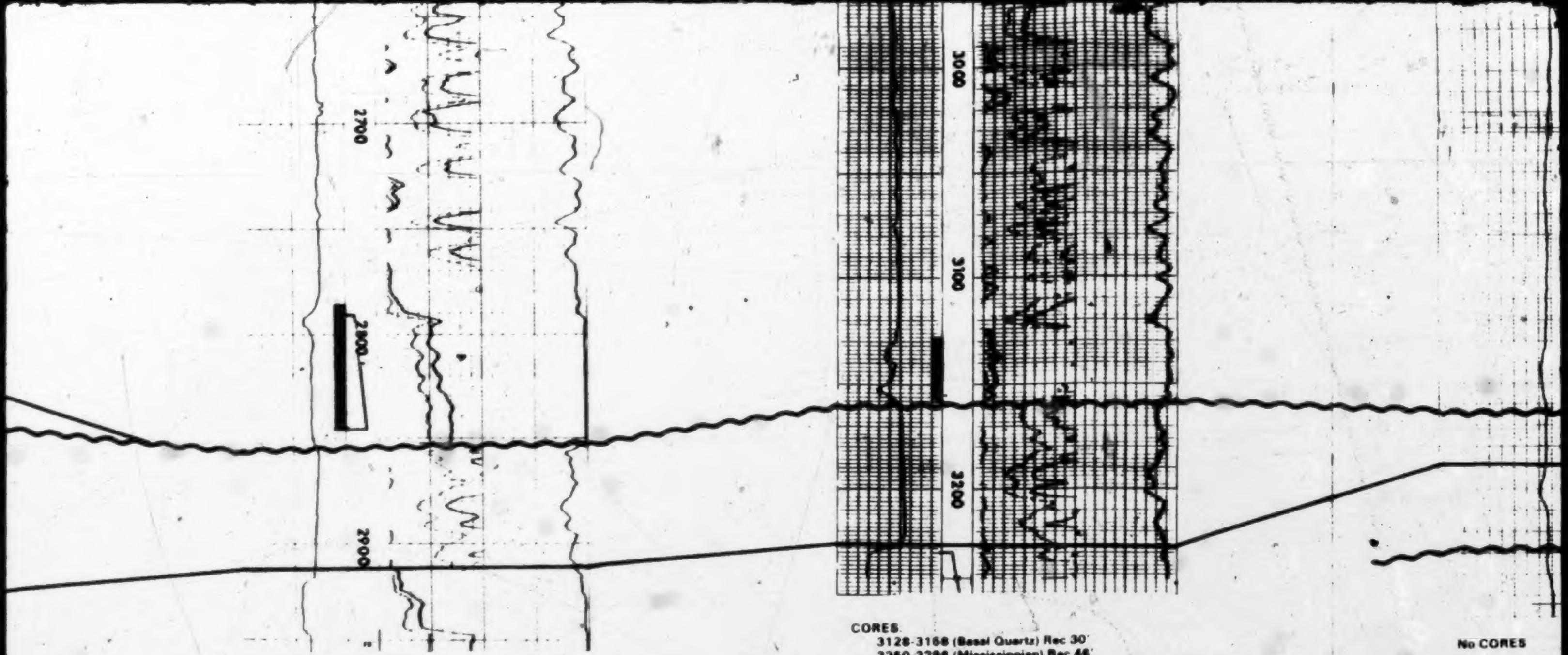
CORES:
3020-3079 (58')

No PERFS

1. 3020-3079 VO 60 SI 60/30 Rec 15' M. HP 1483-1483 FP 43-43 SIP 1059-747
2. 3190-3210 VO 60 SI 60/60 Rec 2850' sli slty sul W, 100' M. HP 1641-1631 FP 485-1314 SIP 1430-1430

3. 3254-3300 VO 30 SI 60/60 WTS in 15 min., sul & slty. Rec 3300' slty sul gsy W. HP 1732-1729 FP 1159-1422 SIP 1466-1466

12 of



CORES:
2786-2845

No PERFS

2. 2791-2845 VO 5 hrs. SI 60 & 120 mins. Rec 20′ O, 30′ OCM FP 20 HP 1520 SIP 50

CORES.
3128-3158 (Basal Quartz) Rec 30′
3250-3296 (Mississippian) Rec 46′

No PERFS

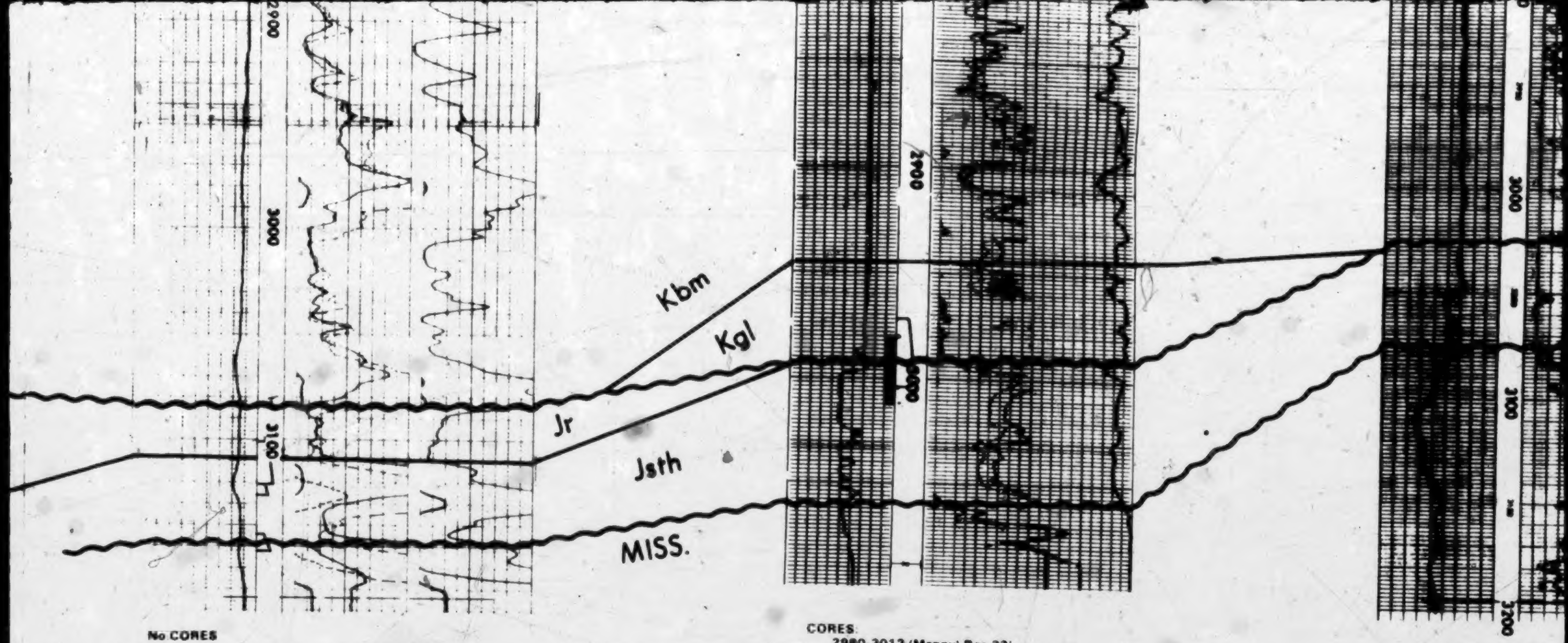
1. 3230-3296 (Jur/Miss) PF 5 VO 60 SI 10/30. SAB. Flt$ 8″. Rec 3230′ sul SW. 12,400 ppm Cl. HP 1661-1625 FP 1386-1459 SIP 1486-1495

No CORES

No PERFS

3. 2406-18 VO
VSAB dying
& 2130′ or
1100 FP 50
4. 2451-71 V
.84 bbls. M
1550 FP 30
5. 3101-3121
thru-out tes
HP 1950 F
6. 3121-26 V
WAB. 110′
5.17 bbls. s
200
7. 3144-52 V
M

13 of



No CORES

No PERFS

3. 2405-15 VO 30 mins. Shut in 15 mins. GIP, VSAB dying in 10 mins. Rec 30' or .42 bbls M & 2130' or 29.82 bbls slty W. HP 1500 SIP 1100 FP 500-1000
4. 2451-71 VO 15 mins GIP, GAB. Rec 60' or .84 bbls. M 1350' or 18.90 bbls. SW. HP 1550 FP 300-700 SIP 925
5. 3101-3121 VO 1½ hr. GIP, WAB contin. thru-out test. Rec 65' or .91 bbls. hvly OCM. HP 1960 FP 0
6. 3121-26 VO 1½ hr. Shut in 15 mins. GIP, WAB. 110' or 1.54 bbls. sli OCM. 369' or 5.17 bbls. sul. SW. HP 1950 SIP 1525 FP 200
7. 3144-52 VO 30 mins. Rec 200' or 2.80 bbls M

CORES:
2980-3012 (Mannv) Rec 32'

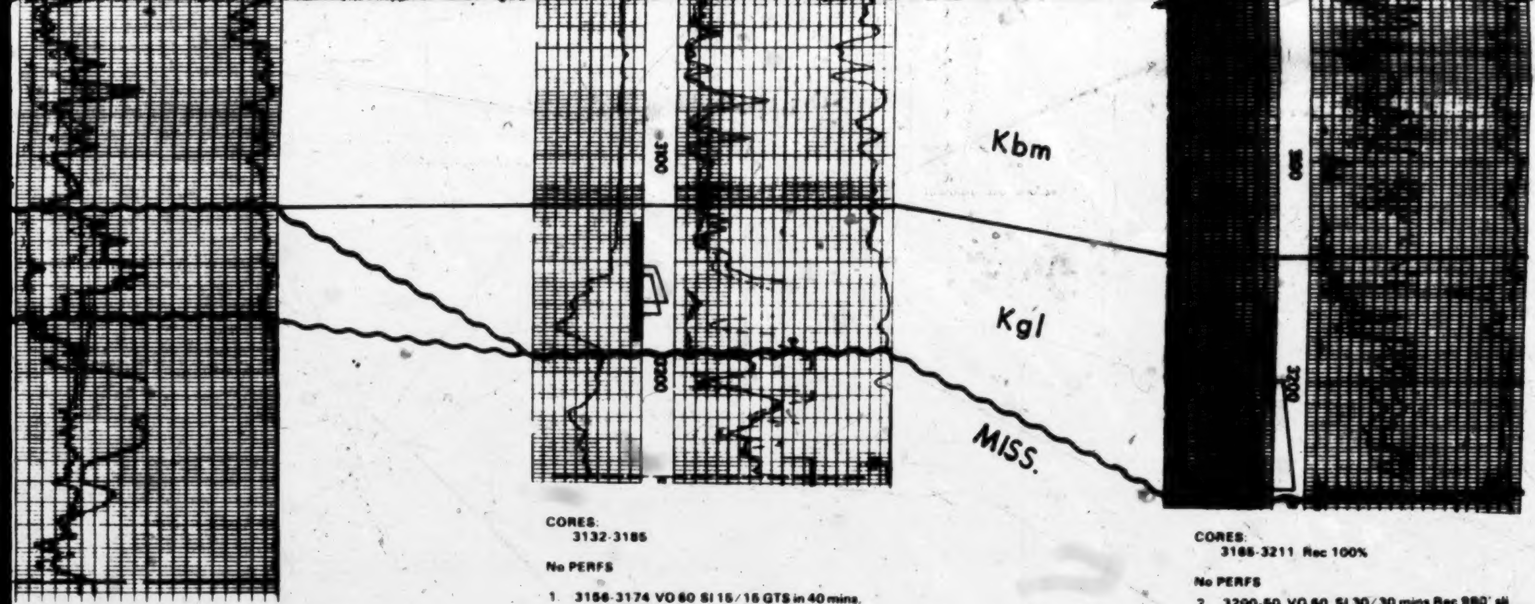
No PERFS

1. 2972-3004 (Mannv) VO 5/60 SI 60/90 SIP on PF, GB on VO, no GTS. Rec 500' O stained mdy W. 1900' O stained W. HP 1626-1626 FP 369-1059 SIP 1481-1430

No CORES

PERFS:
Open Hole Comple
Treatment

No DST's



Completion 3040-3067 No

CORES:
3132-3185

No PERFS

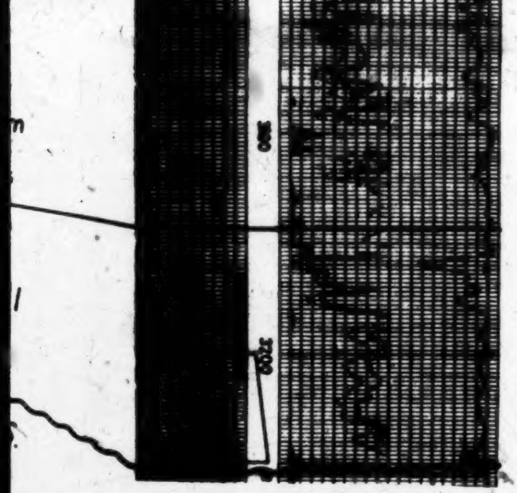
1. 3156-3174 VO 60 SI 15/15 GTS in 40 mins, TSTM, WTS in 49 min, Rec 2200' SW, 800' OCSW HP 1806-1806 FP 650-1380 SIP 1560-1537
2. 3152-3169 VO 90 SI 15/20 GTS in 71 min, TSTM, Rec 775' O (6% BS&W) HP 1803 FP 140-247 SIP 1305-1350

CORES:
3185-3211 Rec 100%

No PERFS

2. 3200-50 VO 60 SI 30/30 mins Rec 980' sli gsy SW HP 1790-1765 FP 175-485 SIP 1445-1355

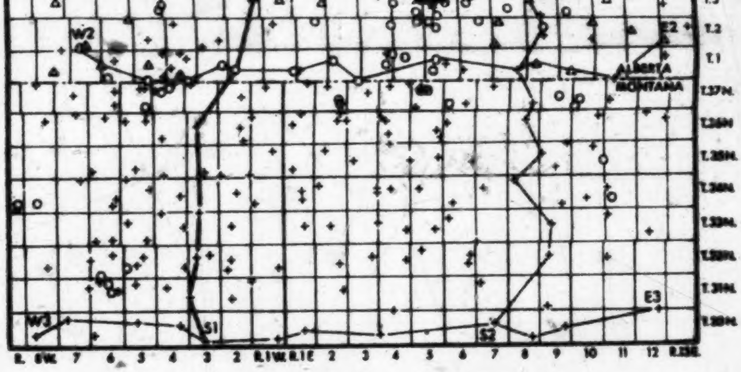
15 of



CORES:
3186-3211 Rec 100%

No PERFS

2. 3200-50 VO 60 SI 30/30 mins Rec 980' sli gsy SW HP 1790-1786 FP 176-485 SIP 1446-1356


W2
E2
ALBERTA
MONTANA
T.2
T.1
T.37N.
W3
S1
S2
E3
R. 8W.
7
6
5
4
3
2
R.1W.R.1E
2
3
4
5
6
7
8
9
10
11
12
R.13E.

CROSS SECTION LOCATION MAP
SOUTHEASTERN ALBERTA-NORTHERN MONTANA

0 5 10 15 20 25 30
MILES (Approx.)

16 of 16

FIGURE 12

STRATIGRAPHIC CROSS SECTION

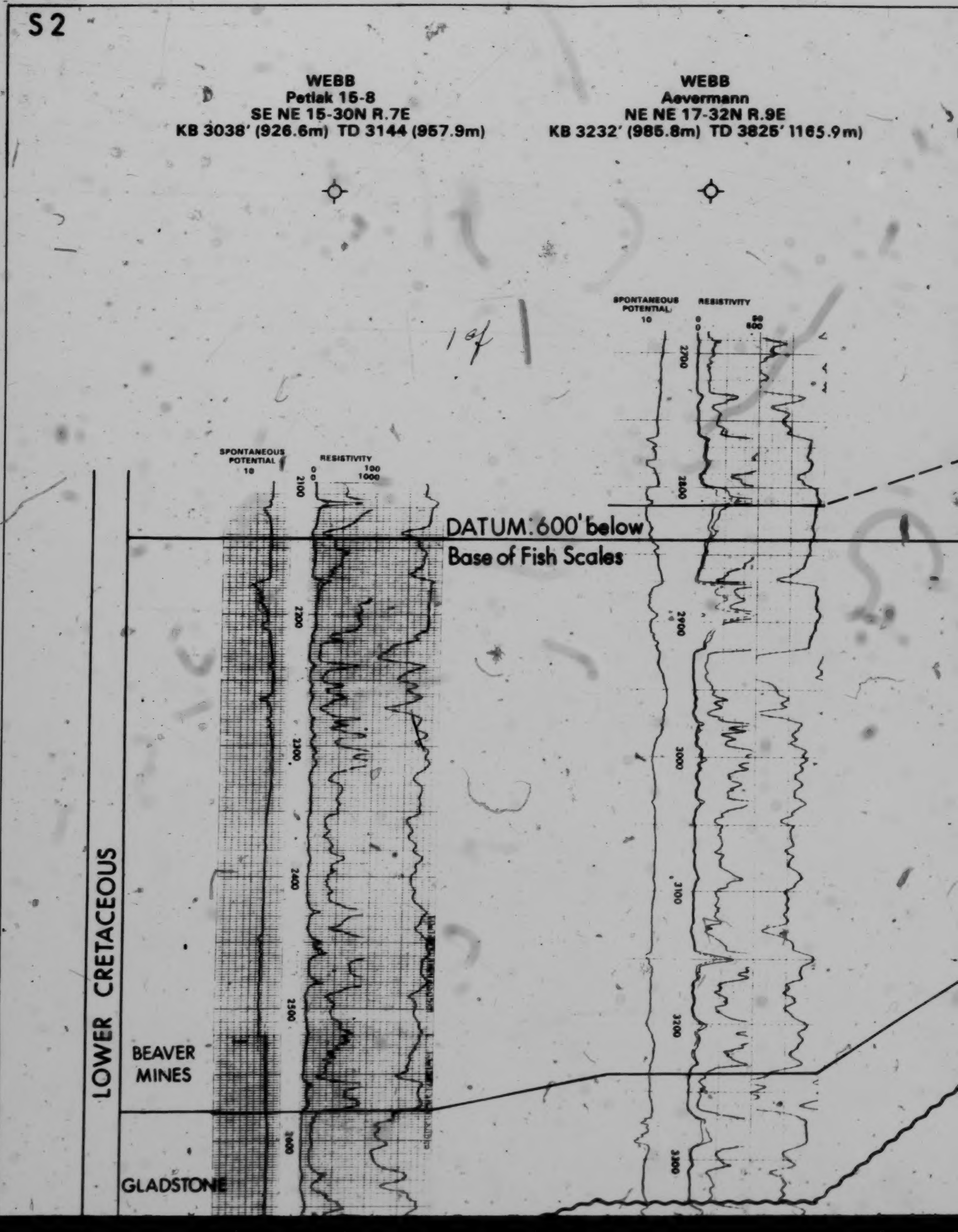
S1-N1

DATUM: 700 feet below Base of Fish Scales.

B. Hayes
University of Alberta
1981

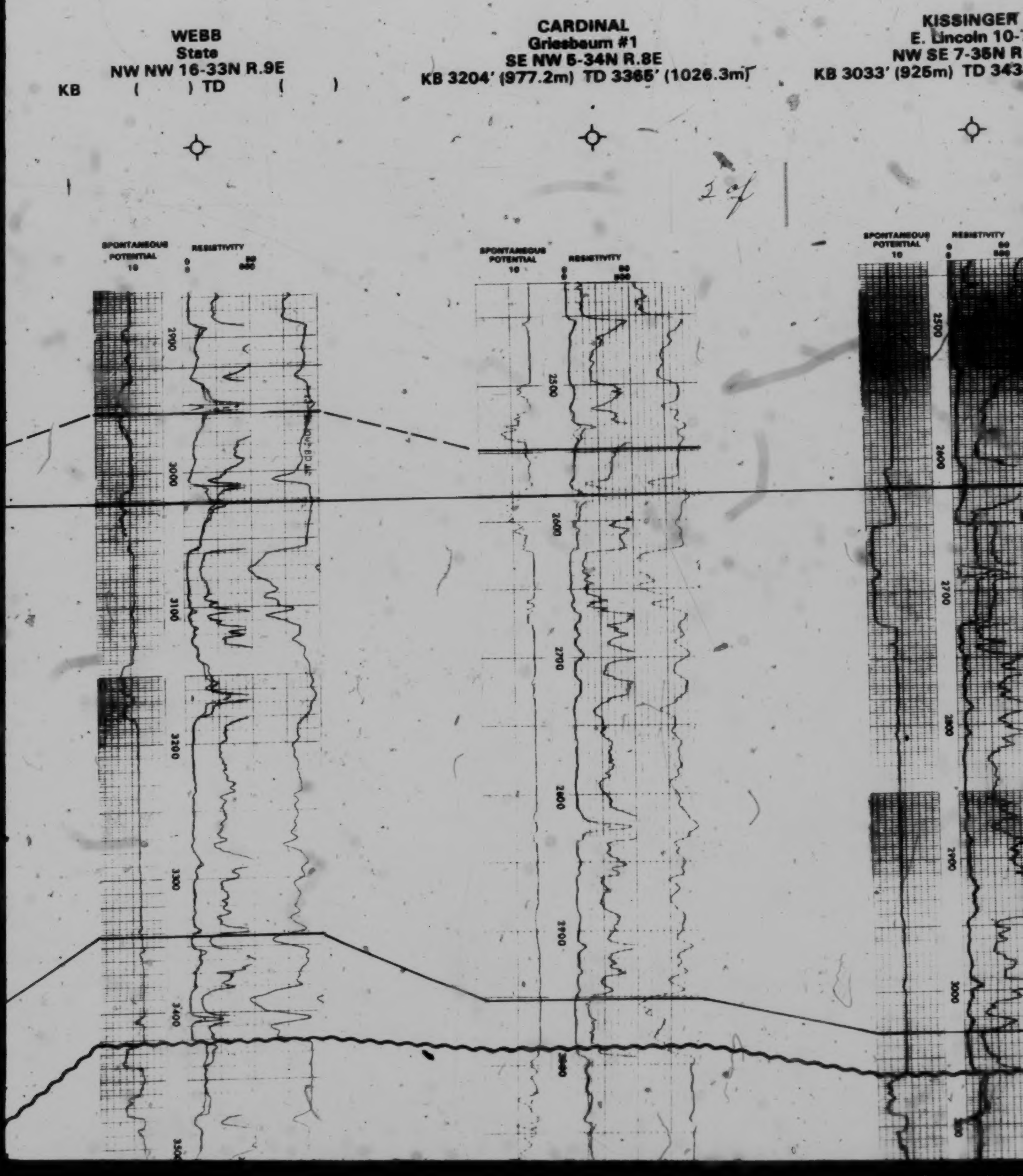
VERTICAL SCALE: 1"= 80'

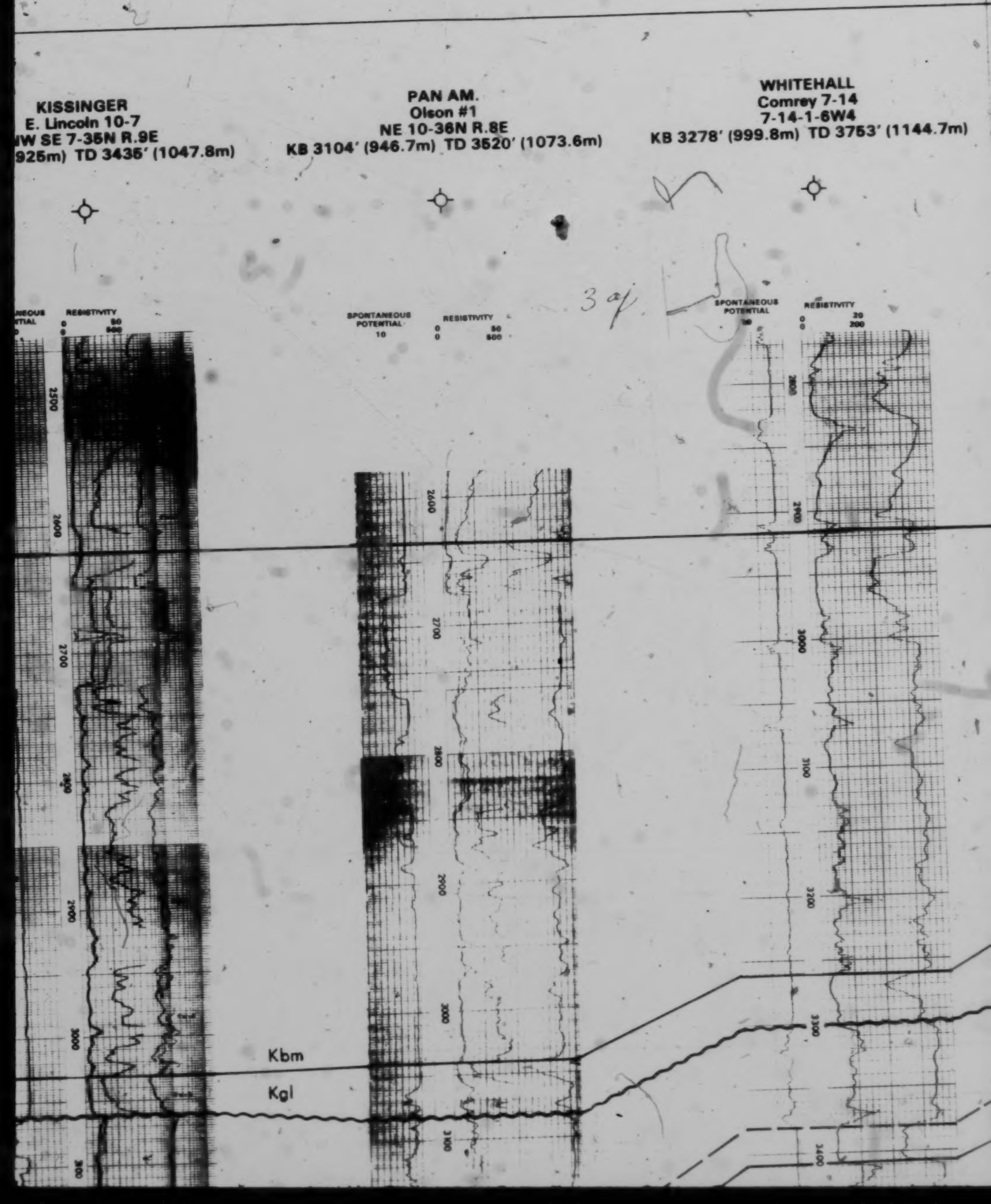
S2

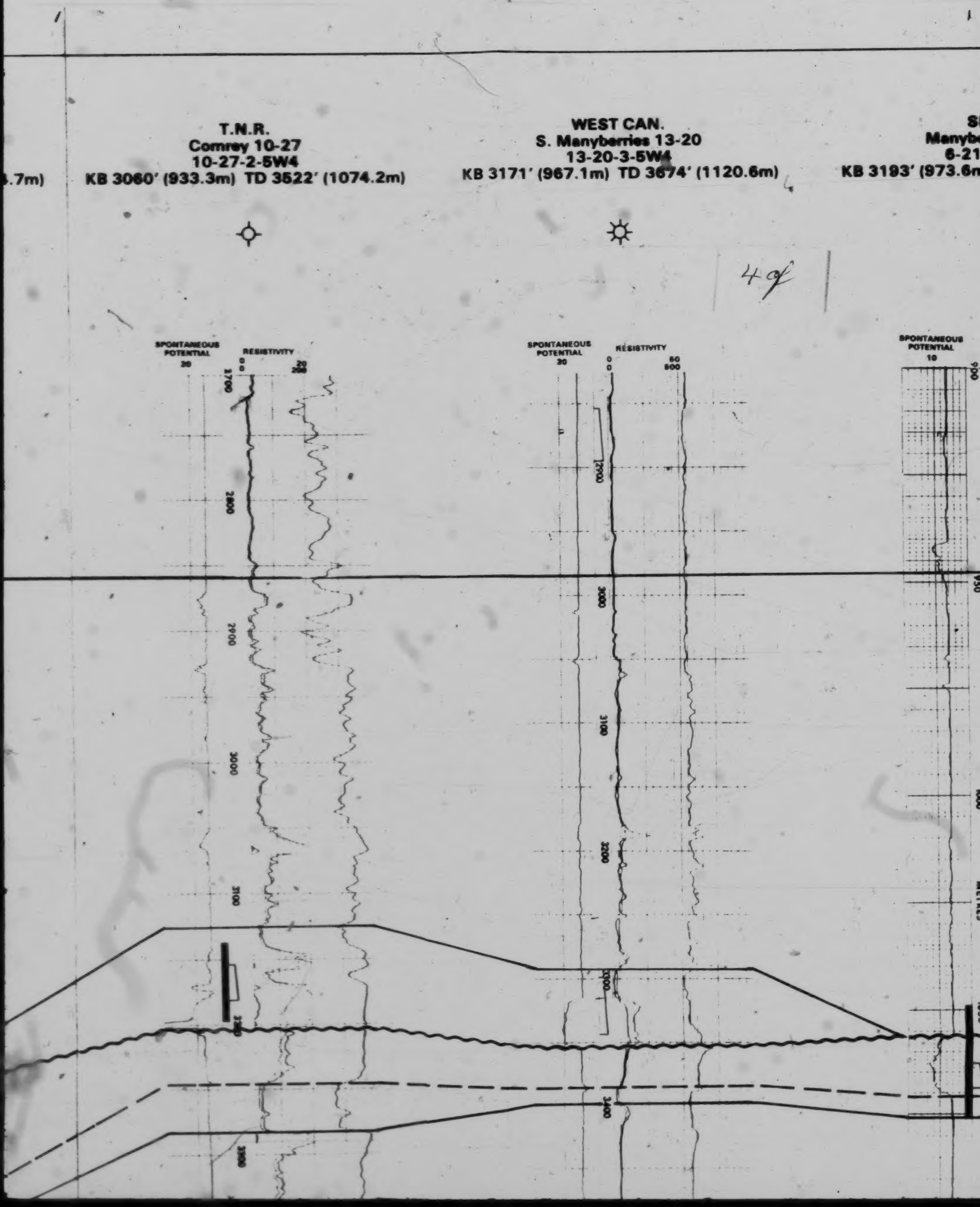


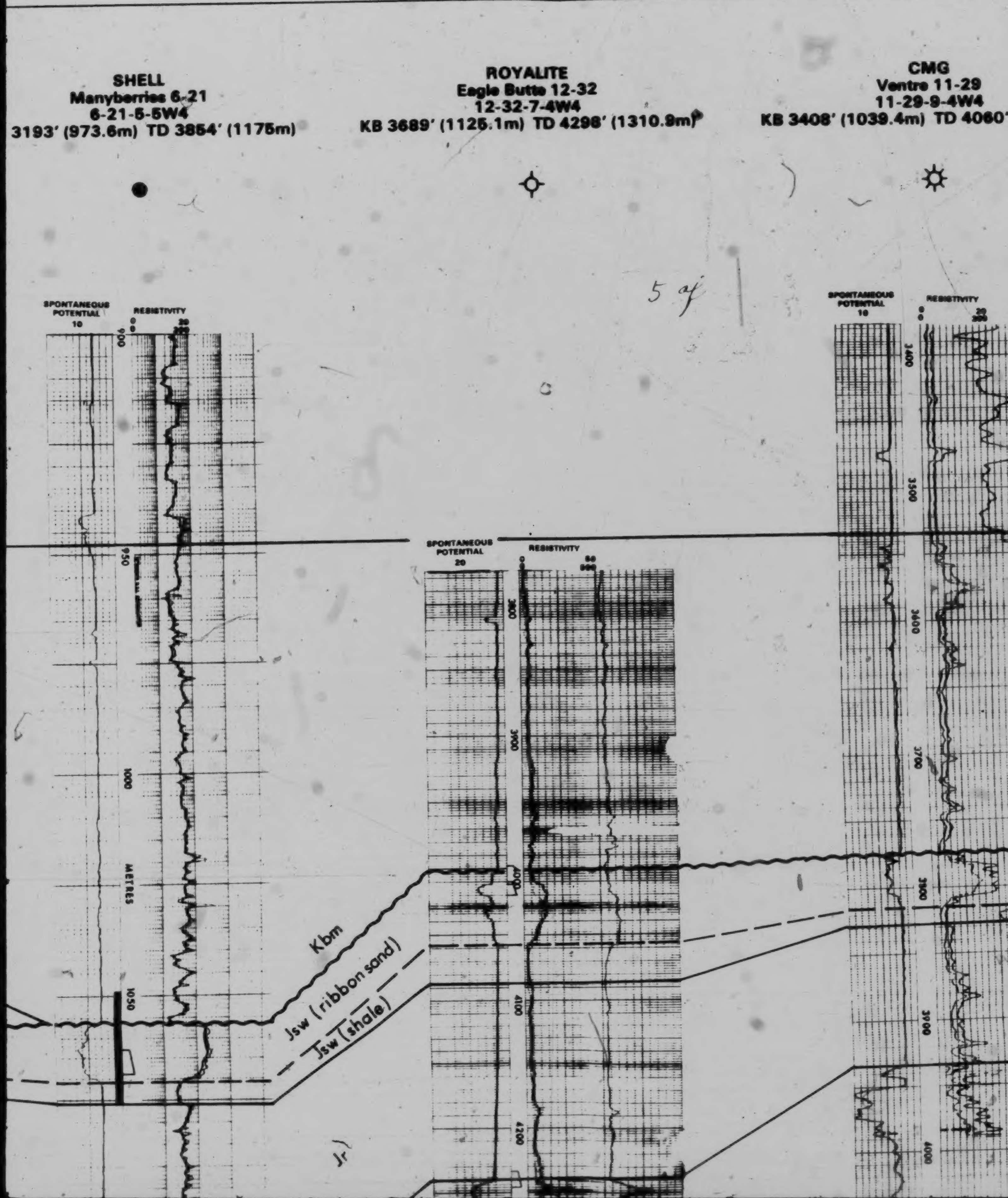
WEBB
Petlak 15-8
SE NE 15-30N R.7E
KB 3038' (926.6m) TD 3144 (957.9m)
WEBB
Aevermann
NE NE 17-32N R.9E
KB 3232' (985.8m) TD 3825' 1165.9m)
SPONTANEOUS POTENTIAL 10
RESISTIVITY 0 100 1000
SPONTANEOUS POTENTIAL 10
RESISTIVITY 0 50 500
2100
2200
2300
2400
2500
2600
2700
2800
2900
3000
3100
3200
3300
DATUM: 600' below Base of Fish Scales
LOWER CRETACEOUS
BEAVER MINES
GLADSTONE

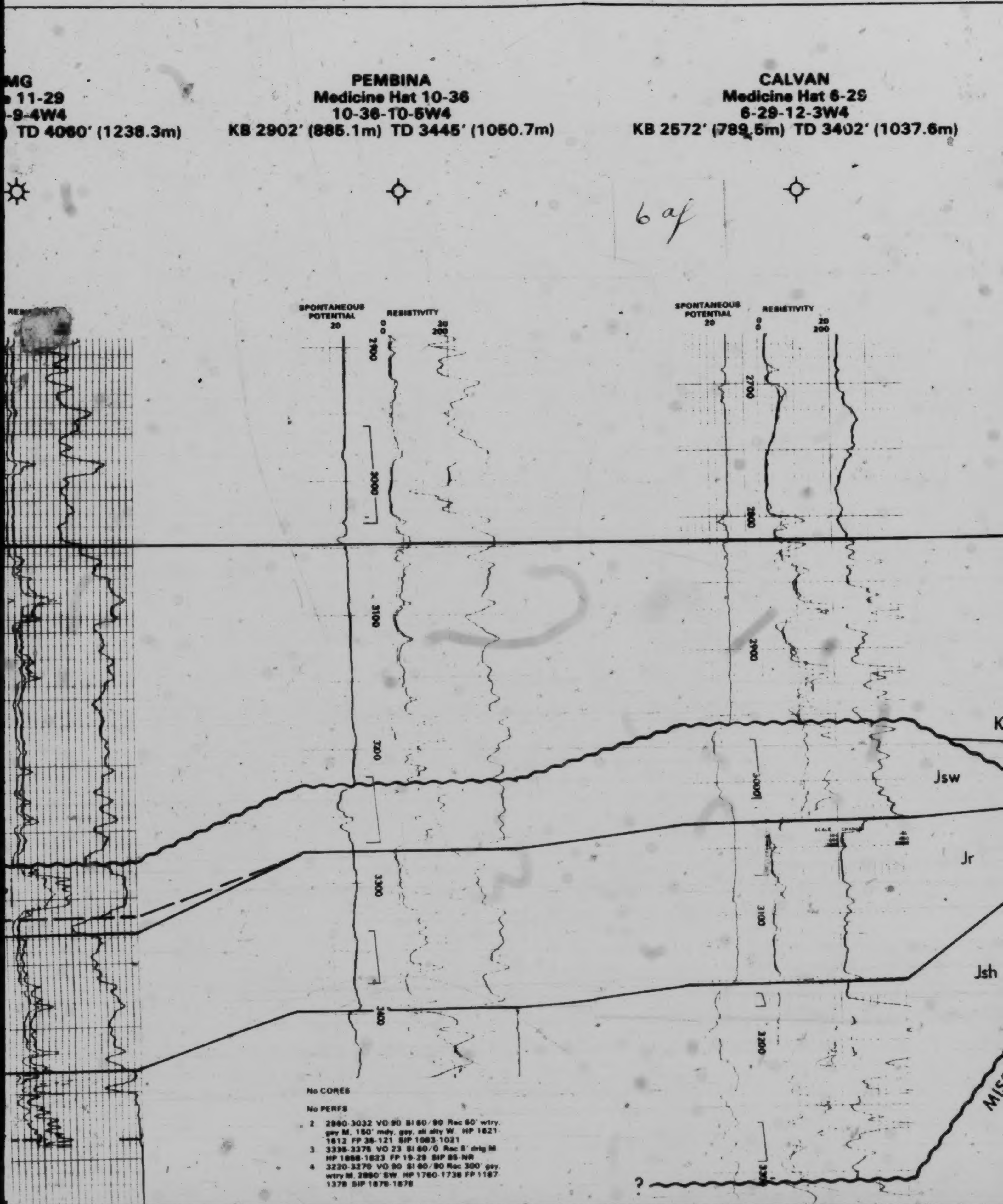
1 of


WEBB
State
NW NW 16-33N R.9E
KB ( ) TD ( )
CARDINAL
Griesbaum #1
SE NW 5-34N R.8E
KB 3204' (977.2m) TD 3365' (1026.3m)
KISSINGER
E. Lincoln 10-
NW SE 7-35N R
KB 3033' (925m) TD 343
2 of
SPONTANEOUS POTENTIAL
10
RESISTIVITY
0
0
50
500
2900
3000
3100
3200
3300
3400
3500
2500
2600
2700
2800
2900
3000
2500
2600
2700
2800
2900
3000


KISSINGER
E. Lincoln 10-7
NW SE 7-35N R.9E
925m) TD 3435' (1047.8m)
PAN AM.
Olson #1
NE 10-36N R.8E
KB 3104' (946.7m) TD 3520' (1073.6m)
WHITEHALL
Comrey 7-14
7-14-1-6W4
KB 3278' (999.8m) TD 3753' (1144.7m)
3 aj
SPONTANEOUS POTENTIAL
RESISTIVITY
0 50
0 500
10
0 20
0 200
2500
2600
2700
2800
2900
3000
3100
3200
3300
3400
Kbm
Kgl


.7m)
T.N.R.
Comrey 10-27
10-27-2-5W4
KB 3060' (933.3m) TD 3522' (1074.2m)
WEST CAN.
S. Manyberries 13-20
13-20-3-5W4
KB 3171' (967.1m) TD 3674' (1120.6m)
S
Manyb
6-21
KB 3193' (973.6m
4f
SPONTANEOUS POTENTIAL
20
RESISTIVITY
0
0
20
200
2700
2800
2900
3000
3100
3200
3300
SPONTANEOUS POTENTIAL
20
RESISTIVITY
0
0
50
500
2900
3000
3100
3200
3300
3400
SPONTANEOUS POTENTIAL
10
900
950
1000
METRES


SHELL
Manyberries 6-21
6-21-5-5W4
3193' (973.6m) TD 3854' (1175m)
ROYALITE
Eagle Butte 12-32
12-32-7-4W4
KB 3689' (1125.1m) TD 4298' (1310.9m)
CMG
Ventre 11-29
11-29-9-4W4
KB 3408' (1039.4m) TD 4060
5 aj
SPONTANEOUS POTENTIAL
10
RESISTIVITY
0
20
200
900
950
1000
METRES
1050
SPONTANEOUS POTENTIAL
20
RESISTIVITY
0
50
500
3800
3900
4000
4100
4200
SPONTANEOUS POTENTIAL
10
RESISTIVITY
0
20
200
3400
3500
3600
3700
3800
3900
4000
Kbm
Jsw (ribbon sand)
Jsw (shale)
Jr

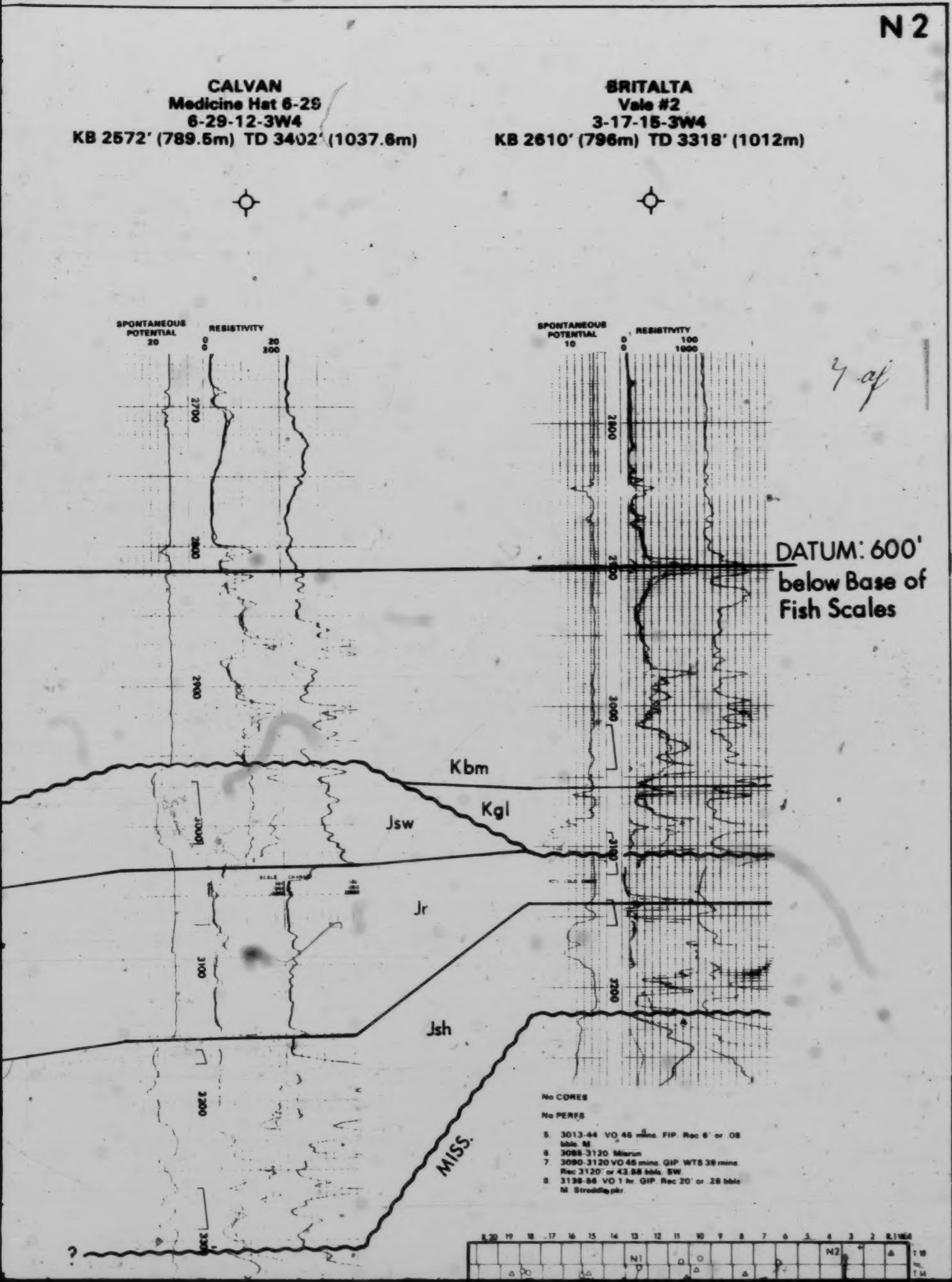

MG
11-29
-9-4W4
TD 4060' (1238.3m)
PEMBINA
Medicine Hat 10-36
10-36-10-5W4
KB 2902' (885.1m) TD 3445' (1050.7m)
CALVAN
Medicine Hat 6-29
6-29-12-3W4
KB 2572' (789.5m) TD 3402' (1037.6m)
SPONTANEOUS POTENTIAL
20
RESISTIVITY
0
20
200
2900
3000
3100
3200
3300
3400
2700
2800
2900
3000
3100
3200
3300
K
Jsw
Jr
Jsh
MIS
?

6 af

No CORES

No PERFS

2 2860-3032 VO 90 SI 60/90 Rec 60' wtry. gsy M. 150' mdy. gsy. sli slty W. HP 1621-1612 FP 38-121 SIP 1083-1021
3 3338-3378 VO 23 SI 60/0 Rec 5' drlg M HP 1868-1823 FP 19-29 SIP 85-NR
4 3220-3270 VO 90 SI 60/90 Rec 300' gsy. wtry M. 2860' SW. HP 1760-1738 FP 1187-1378 SIP 1878-1878

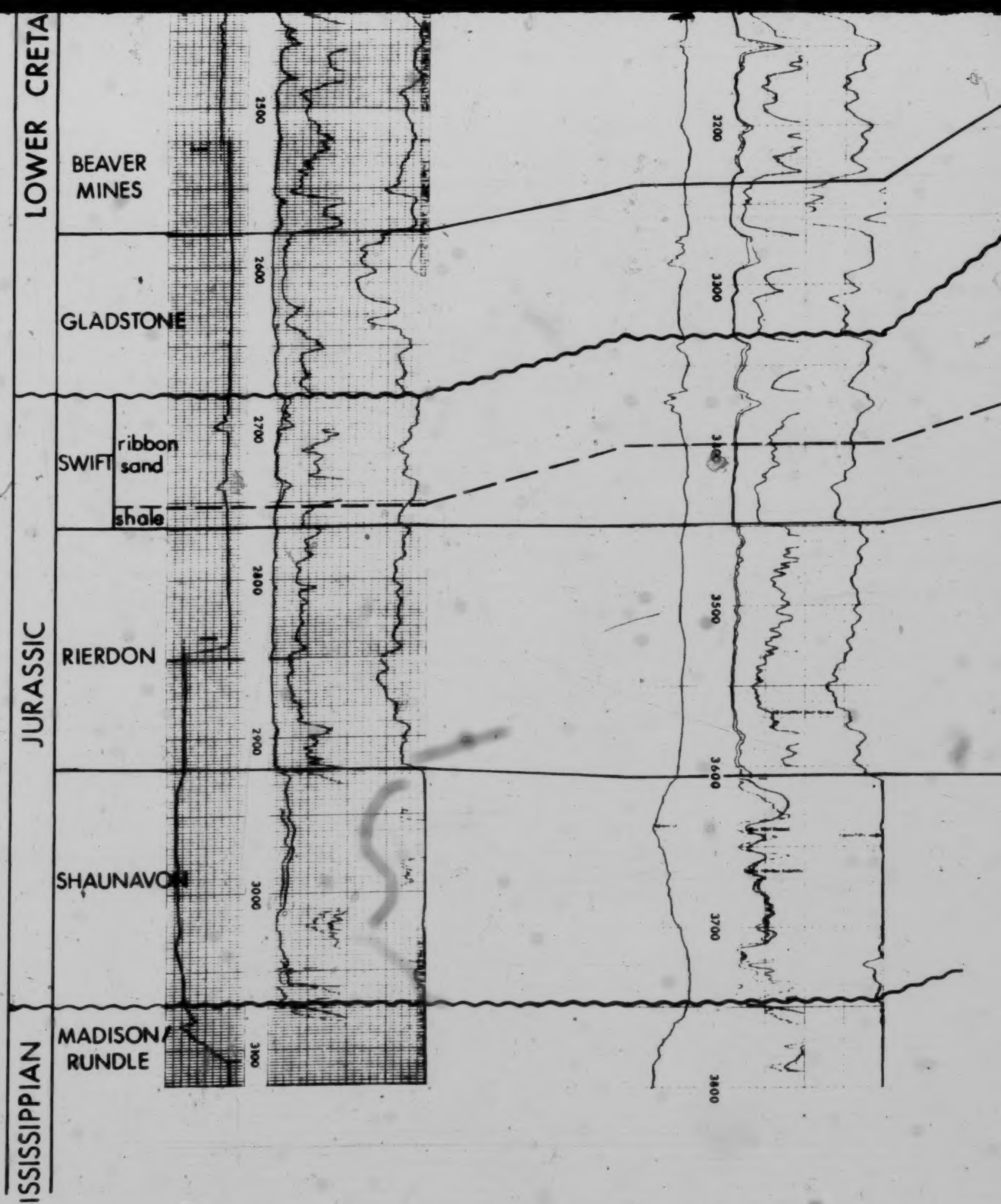

N 2
CALVAN
Medicine Hat 6-29
6-29-12-3W4
KB 2572' (789.5m) TD 3402' (1037.6m)
BRITALTA
Vale #2
3-17-15-3W4
KB 2610' (796m) TD 3318' (1012m)
SPONTANEOUS POTENTIAL
20
RESISTIVITY
0
0
20
300
2700
2800
2900
3000
3100
3200
3300
SPONTANEOUS POTENTIAL
10
RESISTIVITY
0
100
1000
2800
2900
3000
3100
3200
DATUM: 600' below Base of Fish Scales
Kbm
Kgl
Jsw
Jr
Jsh
MISS.
?
SCALE CHANGE
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
N1
N2
T 15
T 14

7 of

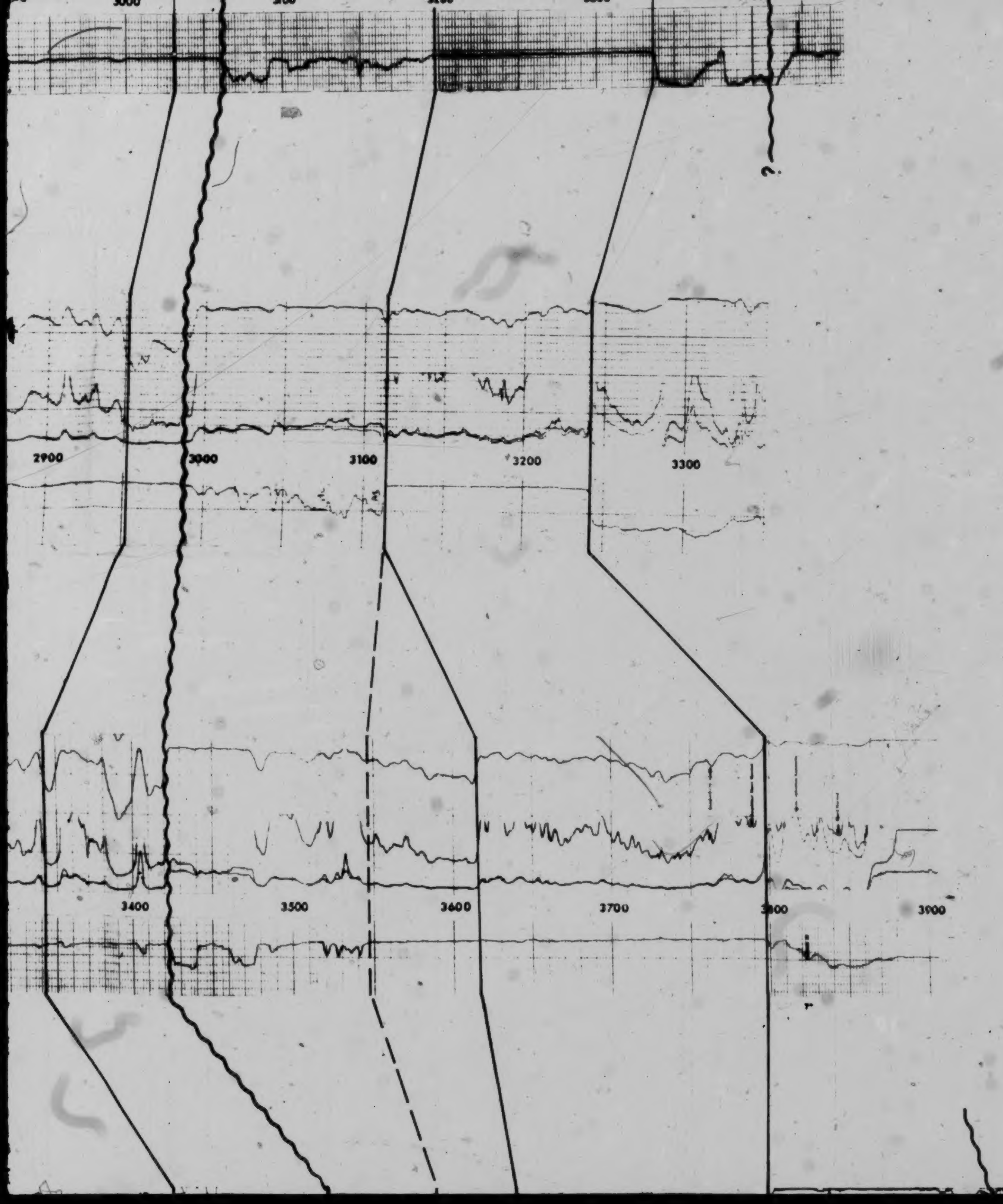
No CORES

No PERFS

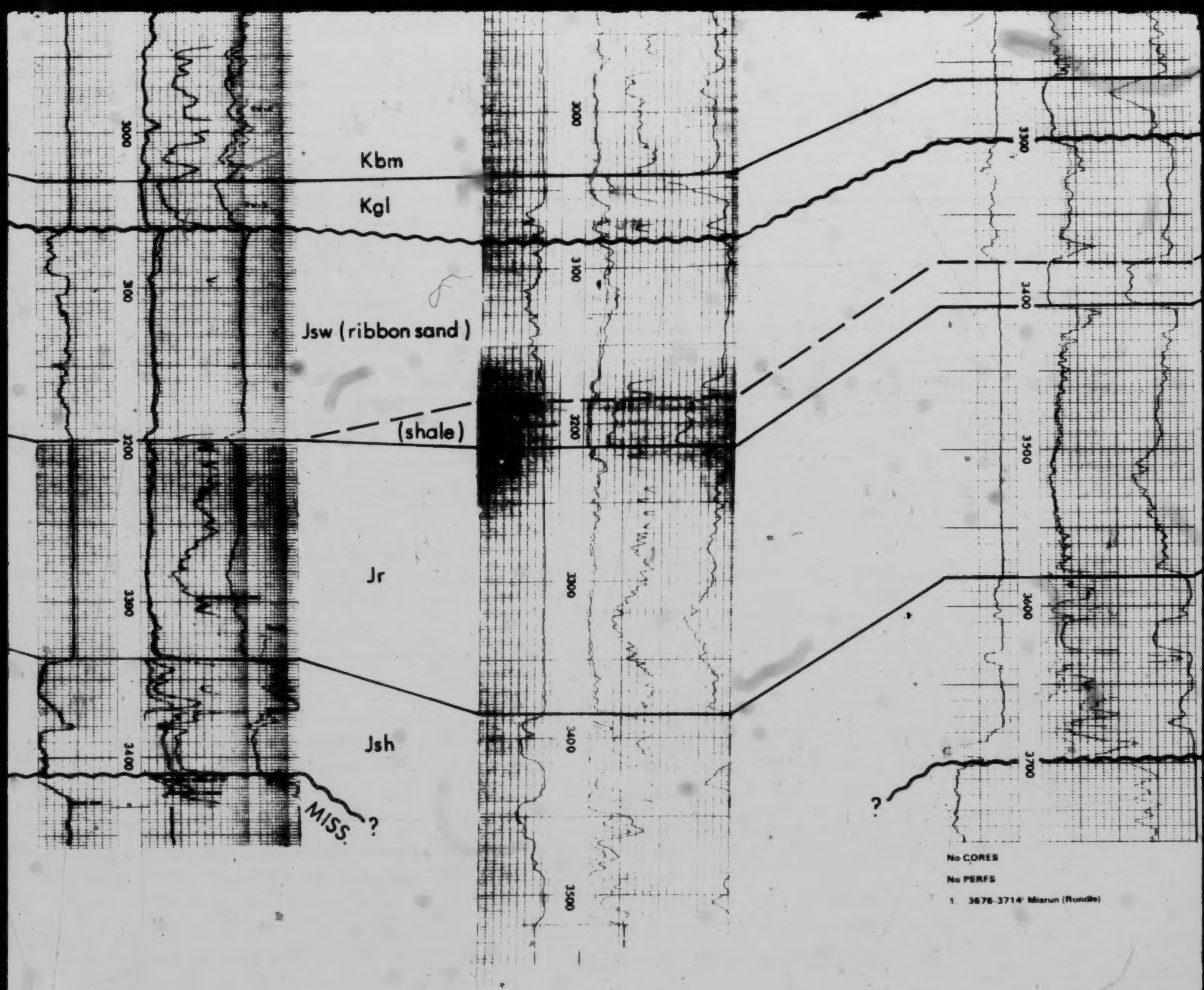
5. 3013-44 VO 45 mins. FIP. Rec 6' or .08 bbls. M.
6. 3088-3120 Misrun
7. 3080-3120 VO 45 mins. GIP. WTS 30 mins. Rec 3120' or 43.88 bbls. SW
8. 3138-56 VO 1 hr. GIP. Rec 20' or .28 bbls M. Straddle pkr.


LOWER CRETA
BEAVER MINES
GLADSTONE
JURASSIC
SWIFT
ribbon sand
shale
RIERDON
SHAUNAVON
MISSISSIPPIAN
MADISON/RUNDLE
2500
2600
2700
2800
2900
3000
3100
3200
3300
3400
3500
3600
3700
3800

8 of


?
2900
3000
3100
3200
3300
3400
3500
3600
3700
3800
3900

9 of

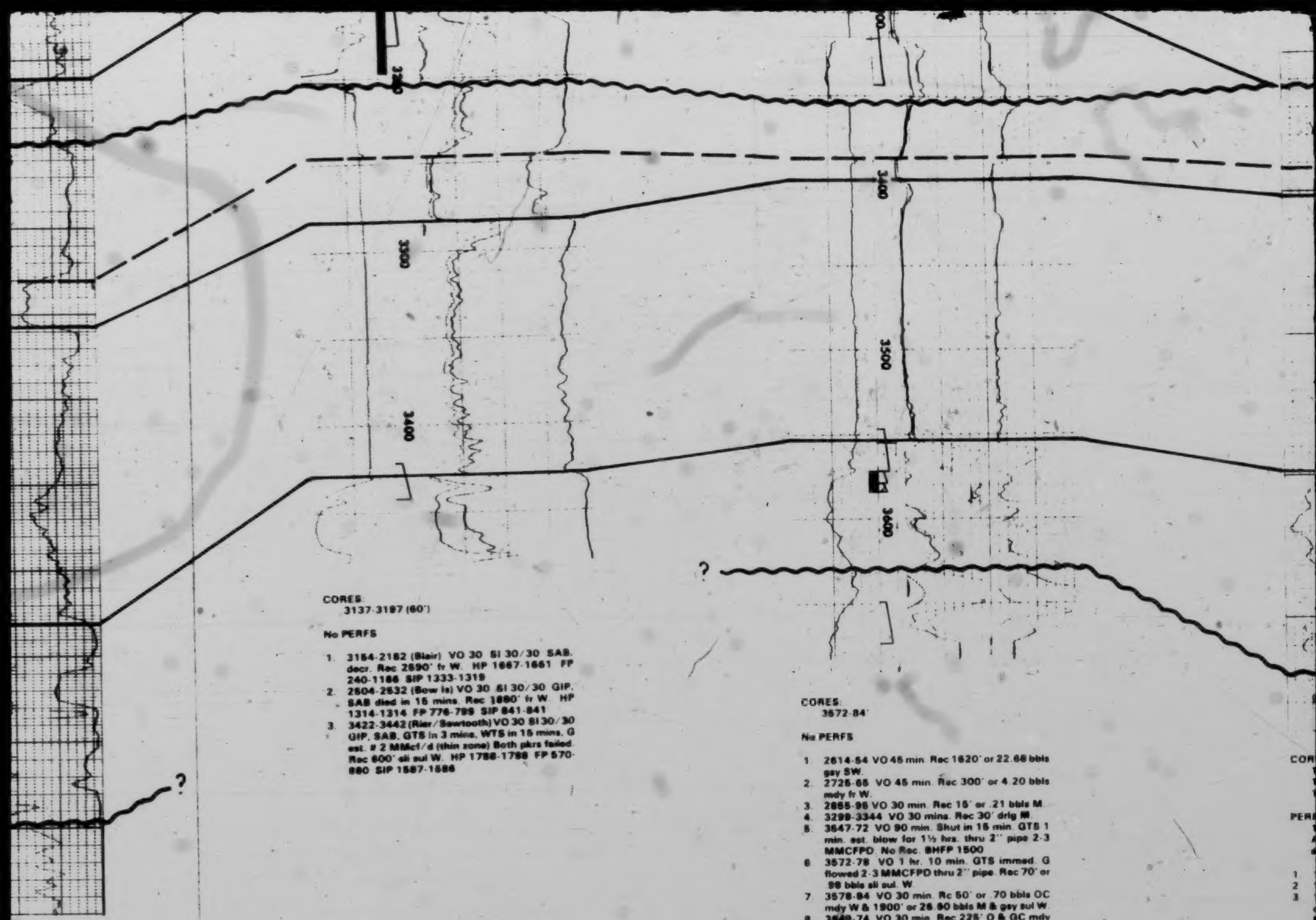

Kbm
Kgl
Jsw (ribbon sand)
(shale)
Jr
Jsh
MISS.
?
?
3000
300
3200
3300
3400
3000
3100
3200
3300
3400
3500
3300
3400
3500
3600
3700

No CORES

No PERFS

1. 3676-3714' Misrun (Rundle)

10 of



CORES:
3137-3197 (60')

No PERFS

1. 3164-2182 (Blair) VO 30 SI 30/30 SAB. decr. Rec 2590' fr W. HP 1667-1661 FP 240-1186 SIP 1333-1319
2. 2504-2532 (Bow Is) VO 30 SI 30/30 GIP. SAB died in 15 mins. Rec 1880' fr W. HP 1314-1314 FP 776-799 SIP 841-841
3. 3422-3442 (Rier/Sawtooth) VO 30 SI 30/30 GIP. SAB. GTS in 3 mins. WTS in 15 mins. G est. # 2 MMcf/d (thin zone) Both pkrs failed. Rec 600' sli sul W. HP 1786-1788 FP 570-880 SIP 1587-1586

CORES:
3672-84'

No PERFS

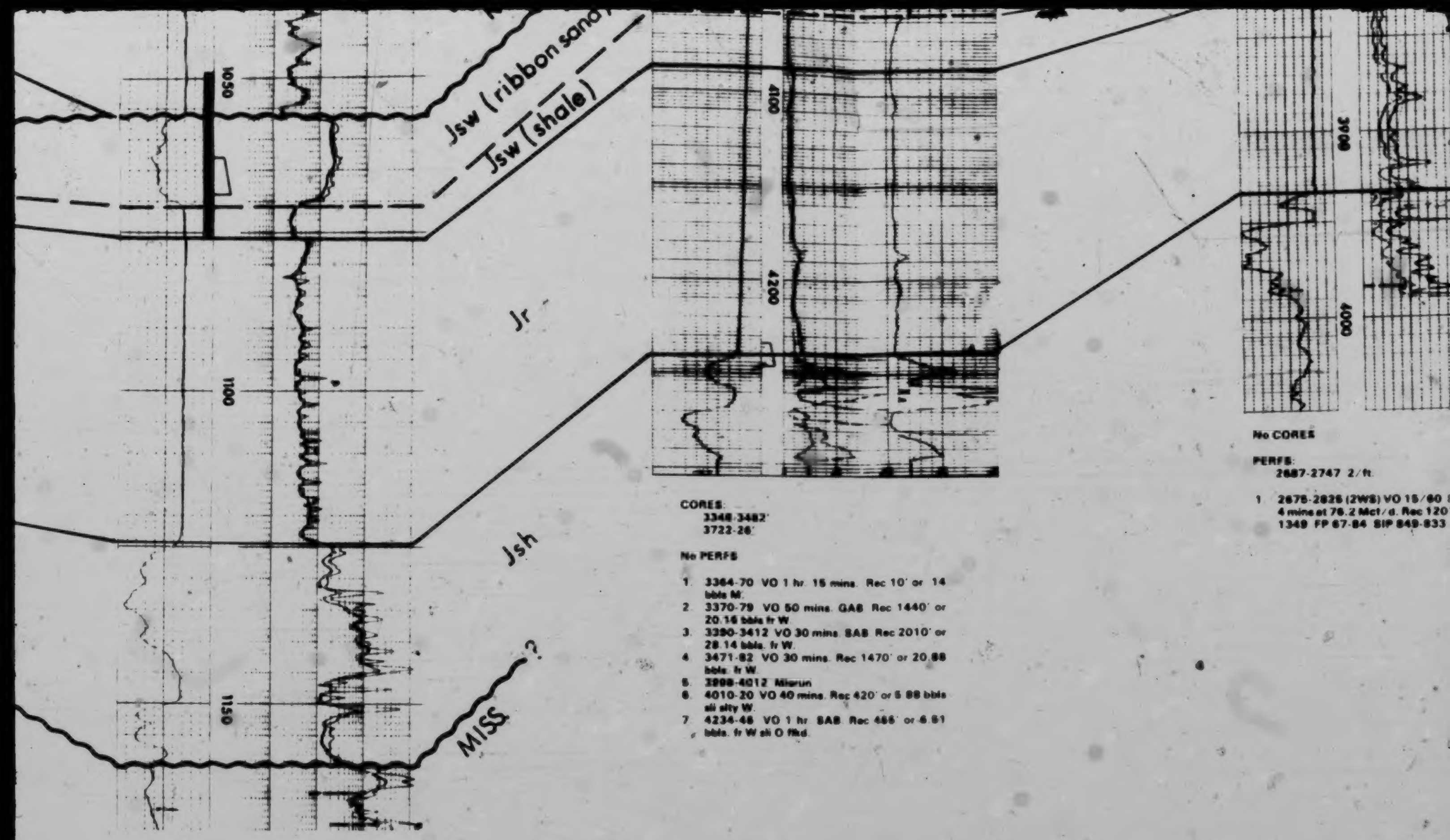
1. 2614-54 VO 45 min. Rec 1620' or 22.68 bbls gsy SW.
2. 2726-66 VO 45 min. Rec 300' or 4.20 bbls mdy fr W.
3. 2865-96 VO 30 min. Rec 15' or .21 bbls M.
4. 3299-3344 VO 30 mins. Rec 30' drlg M.
5. 3647-72 VO 90 min. Shut in 15 min. GTS 1 min. est. blow for 1½ hrs. thru 2'' pipe 2-3 MMCFPD. No Rec. BHFP 1500
6. 3572-78 VO 1 hr. 10 min. GTS immed. G flowed 2-3 MMCFPD thru 2'' pipe. Rec 70' or .98 bbls sli sul. W.
7. 3578-84 VO 30 min. Rc 50' or .70 bbls OC mdy W & 1900' or 26.60 bbls M & gsy sul W.
8. 3640-74 VO 30 min. Rec 225' O & GC mdy W.

COR

PERI

1
2
3

11 of



CORES:
1049-1058 Rec 7m
1058-1067 Rec 9m
1067-1076 Rec 6.3m

PERFS:
1056-1063.5 12/m, sand frac. Swbd, no flow Acid with 2800L acid, (P) 3.65 m3 O/d, with sli amounts of G.

1. 1063-1069 Misrun, bottom pkr failed
2. 1063-1069 Misrun, bottom pkr failed
3. 1063-1069 (B.Q.) VO 5/60 SI 30/90 WAB on PF, WAB incr to GAB after 5 mins on VO. No GTS. Rec 3m MCO, 34m OWCM. HP 12284-11203 FP 327-490 SIP 7659-8228

CORES:
3348-3482'
3722-28'

No PERFS

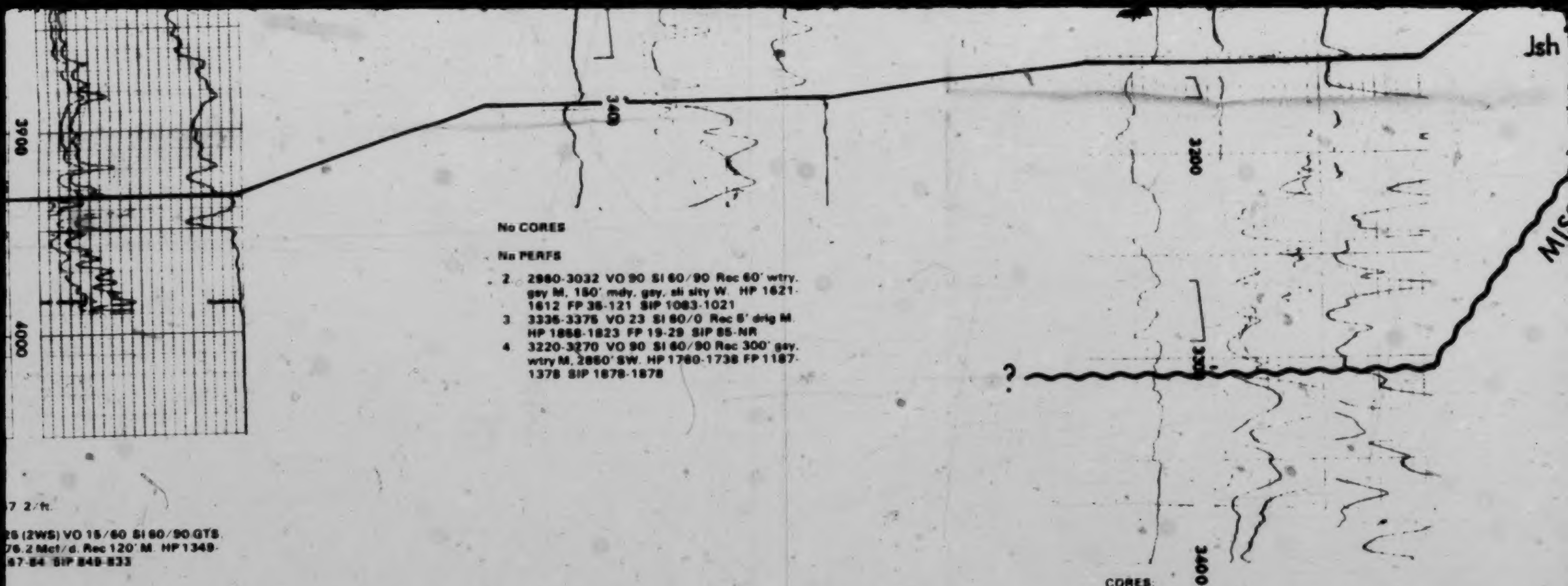
1. 3364-70 VO 1 hr. 15 mins. Rec 10' or 14 bbls M.
2. 3370-79 VO 50 mins. GAB Rec 1440' or 20.16 bbls fr W.
3. 3390-3412 VO 30 mins. SAB Rec 2010' or 28.14 bbls. fr W.
4. 3471-82 VO 30 mins. Rec 1470' or 20.88 bbls. fr W.
5. 3998-4012 Misrun
6. 4010-20 VO 40 mins. Rec 420' or 5.88 bbls sli silty W.
7. 4234-46 VO 1 hr. SAB. Rec 465' or 6.51 bbls. fr W sli O flkd.

No CORES

PERFS:
2687-2747 2/ft.

1. 2675-2826 (2WS) VO 15/60
4 mins at 76.2 Mcf/d. Rec 120
1349 FP 67-84 SIP 849-833

12 of



7 2/ft.

26 (2WS) VO 15/60 SI 60/90 GTS.
76.2 Mcf/d. Rec 120' M. HP 1349-
67-64 SIP 849-833

No CORES

No PERFS

2. 2980-3032 VO 90 SI 60/90 Rec 60' wtry. gsy M, 150' mdy. gsy. sli slty W. HP 1621-1612 FP 36-121 SIP 1083-1021
3. 3336-3376 VO 23 SI 60/0 Rec 5' drlg M. HP 1858-1823 FP 19-29 SIP 85-NR
4. 3220-3270 VO 90 SI 60/90 Rec 300' gsy. wtry M, 2860' SW. HP 1760-1738 FP 1187-1378 SIP 1878-1878

CORES:
2329-2368'

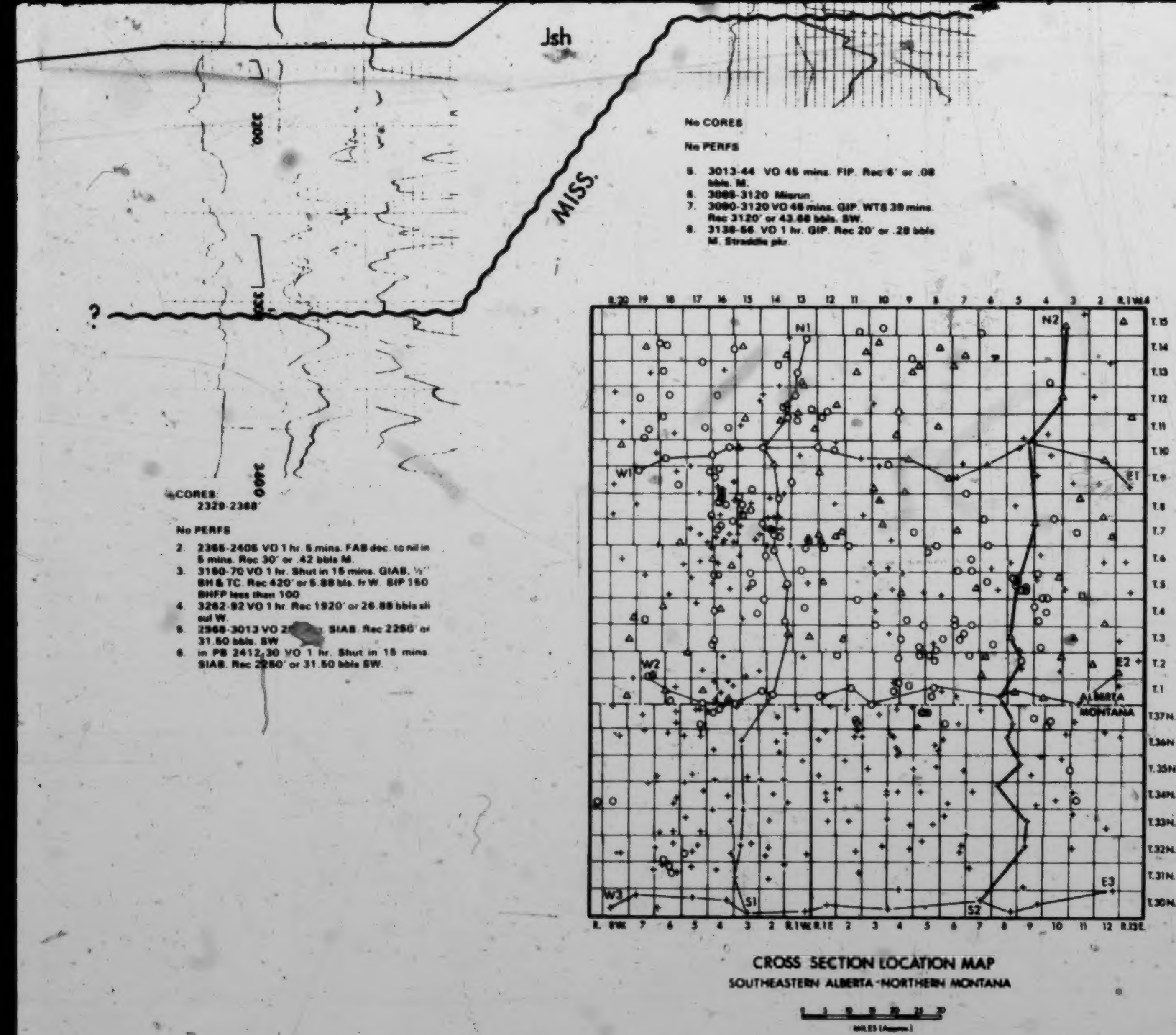
No PERFS

2. 2368-2405 VO 1 hr. 5 mins. FAB dec. to nil in 5 mins. Rec 30' or .42 bbls M.
3. 3160-70 VO 1 hr. Shut in 15 mins. GIAB, ½" BH & TC. Rec 420' or 5.88 bls. fr W. SIP 150 BHFP less than 100
4. 3262-92 VO 1 hr. Rec 1920' or 26.88 bbls sli sul W.
5. 2968-3013 VO 25 mins. SIAB. Rec 2250' or 31.50 bbls. SW
6. in PB 2412-30 VO 1 hr. Shut in 15 mins. SIAB. Rec 2250' or 31.50 bbls SW.

13 of

ST

VERT



No CORES

No PERFS

5. 3013-44 VO 45 mins. FIP. Rec 6' or .08 bbls. M.
6. 3086-3120 Misrun
7. 3090-3120 VO 45 mins. GIP. WTS 39 mins. Rec 3120' or 43.68 bbls. SW.
8. 3138-56 VO 1 hr. GIP. Rec 20' or .28 bbls M. Straddle pkr.

CORES
2329-2368'

No PERFS

2. 2366-2405 VO 1 hr. 5 mins. FAB dec. to nil in 5 mins. Rec 30' or .42 bbls M.
3. 3160-70 VO 1 hr. Shut in 15 mins. GIAB. ½" BH & TC. Rec 420' or 5.88 bls. fr W. SIP 150 BHFP less than 100
4. 3262-92 VO 1 hr. Rec 1920' or 26.88 bbls sli sul W.
5. 2968-3013 VO 2[illegible] SIAB. Rec 2250' or 31.50 bbls. SW
6. in PB 2412-30 VO 1 hr. Shut in 15 mins. SIAB. Rec 2250' or 31.50 bbls SW.

CROSS SECTION LOCATION MAP
SOUTHEASTERN ALBERTA - NORTHERN MONTANA

14 of 14

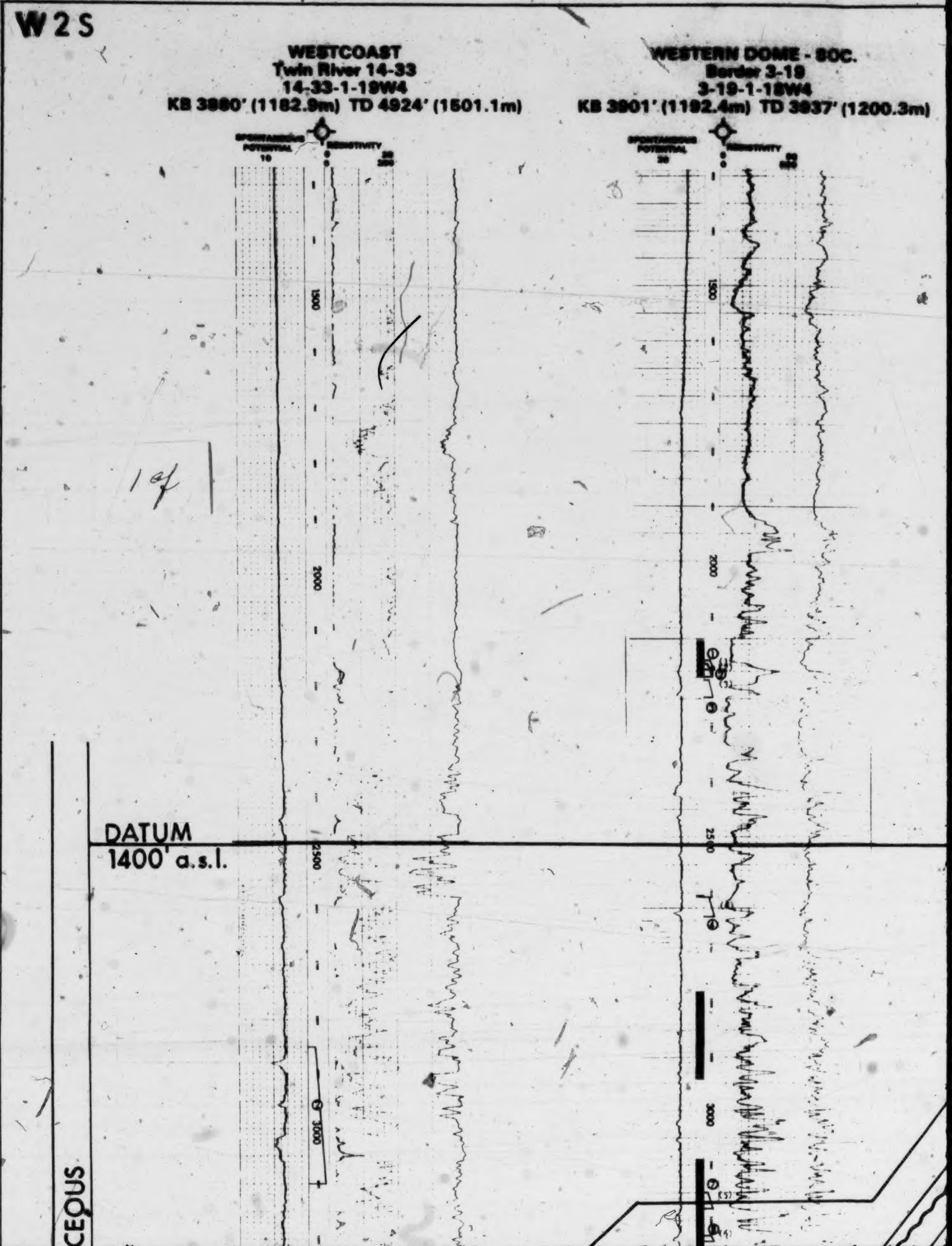
FIGURE 13

STRATIGRAPHIC CROSS SECTION
S2 - N2

DATUM: 600 feet below Base of Fish Scales.

B. Hayes
University of Alberta
1981

VERTICAL SCALE: 1" = 80'

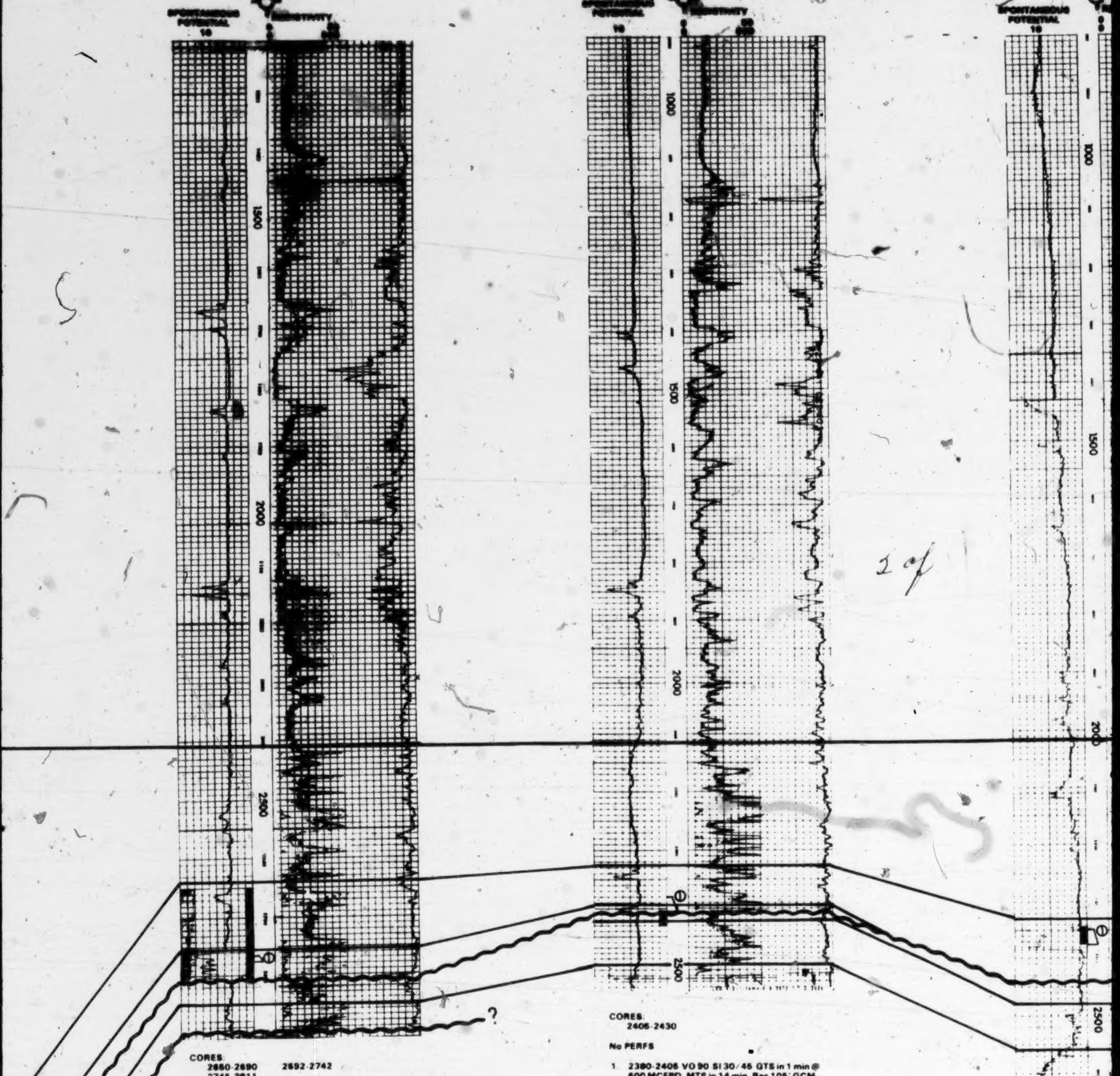

W2S
WESTCOAST
Twin River 14-33
14-33-1-19W4
KB 3880' (1182.9m) TD 4924' (1501.1m)
SPONTANEOUS POTENTIAL
RESISTIVITY
1500
2000
2500
3000
WESTERN DOME - SOC.
Border 3-19
3-19-1-18W4
KB 3901' (1192.4m) TD 3937' (1200.3m)
SPONTANEOUS POTENTIAL
RESISTIVITY
1500
2000
2500
3000
DATUM
1400' a.s.l.
CEOUS
1 of

.3m)

DECALTA
Milk River 2-4
2-4-1-17W4
KB 3808' (1161.0m) TD 2914' (888.8m)

UNION - BUCKLEY
Nuss 4-2
4-2-1-16W4
KB 3512' (1070.8m) TD 2527' (770.5m)

CA
Coutt
11-23
KB 3415' (1041.2m



CORES:
2650-2690 2692-2742
2746-2811

No PERFS

1. 2756-2796 VO 36 SI 60/60 Rec 4' M HP 1645-1653 FP 39-47 SIP 902-1012

CORES:
2406-2430

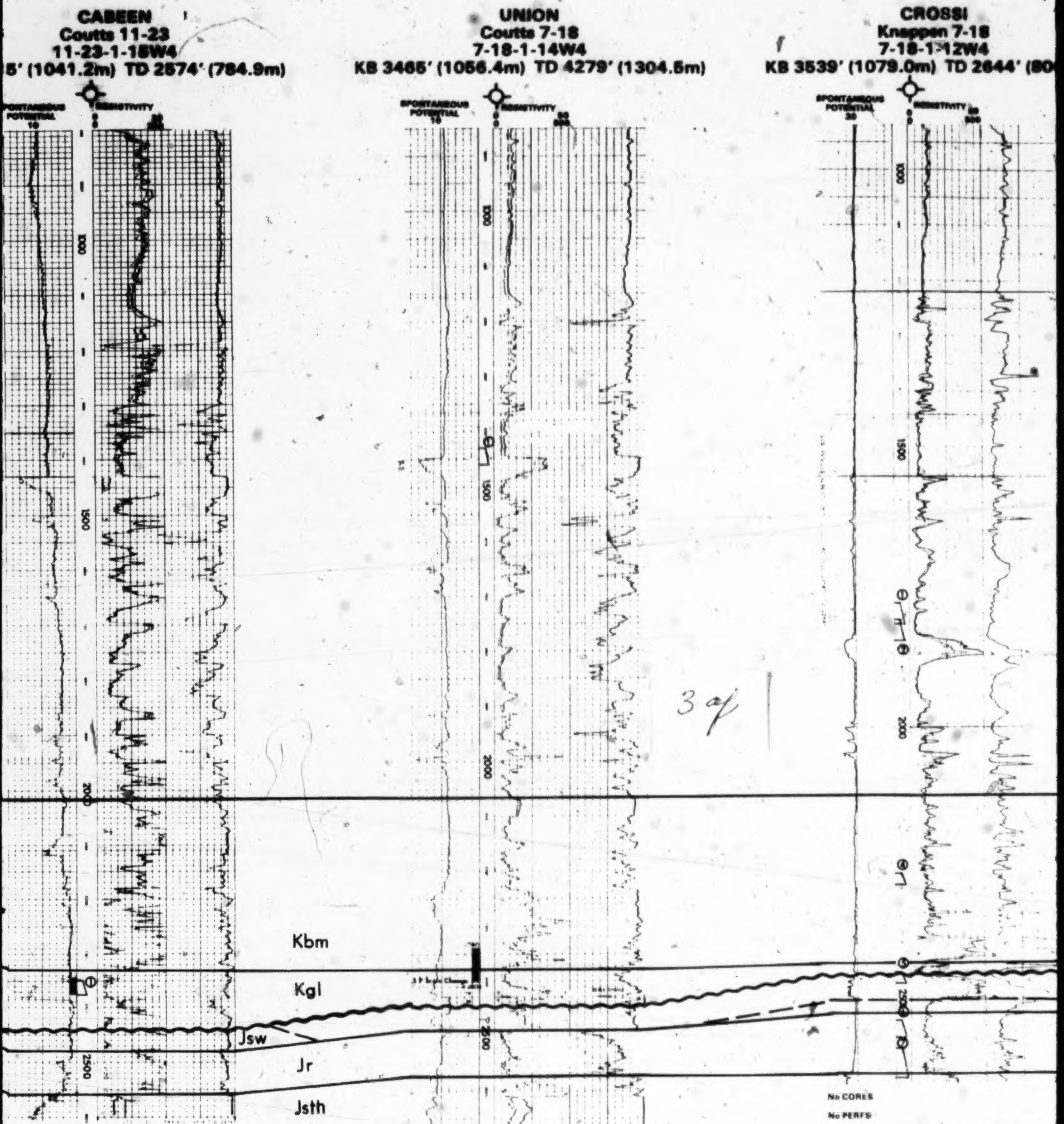
No PERFS

1. 2380-2406 VO 90 SI 30/45 GTS in 1 min @ 600 MCFPD, MTS in 14 min, Rec 105' GCM. HP 1344-1344 FP 192-144 SIP 864-816

CORES:
2344-2374

No PERFS

1. 2348-2375 V
1125 fr W HP
660


CABEEN
Coutts 11-23
11-23-1-15W4
5' (1041.2m) TD 2574' (784.9m)
UNION
Coutts 7-18
7-18-1-14W4
KB 3465' (1056.4m) TD 4279' (1304.5m)
CROSSI
Knappen 7-18
7-18-1-12W4
KB 3539' (1079.0m) TD 2644' (80
SPONTANEOUS POTENTIAL
RESISTIVITY
1000
1500
2000
2500
Kbm
Kgl
Jsw
Jr
Jsth
3 af

CORES:
2344-2374

No PERFS

1. 2348-2375 VO 60 SI 15/15 mins. Rec 1125 fr W. HP 1305-1305 FP 200-470 FSIP 660

CORES:
2340-2400

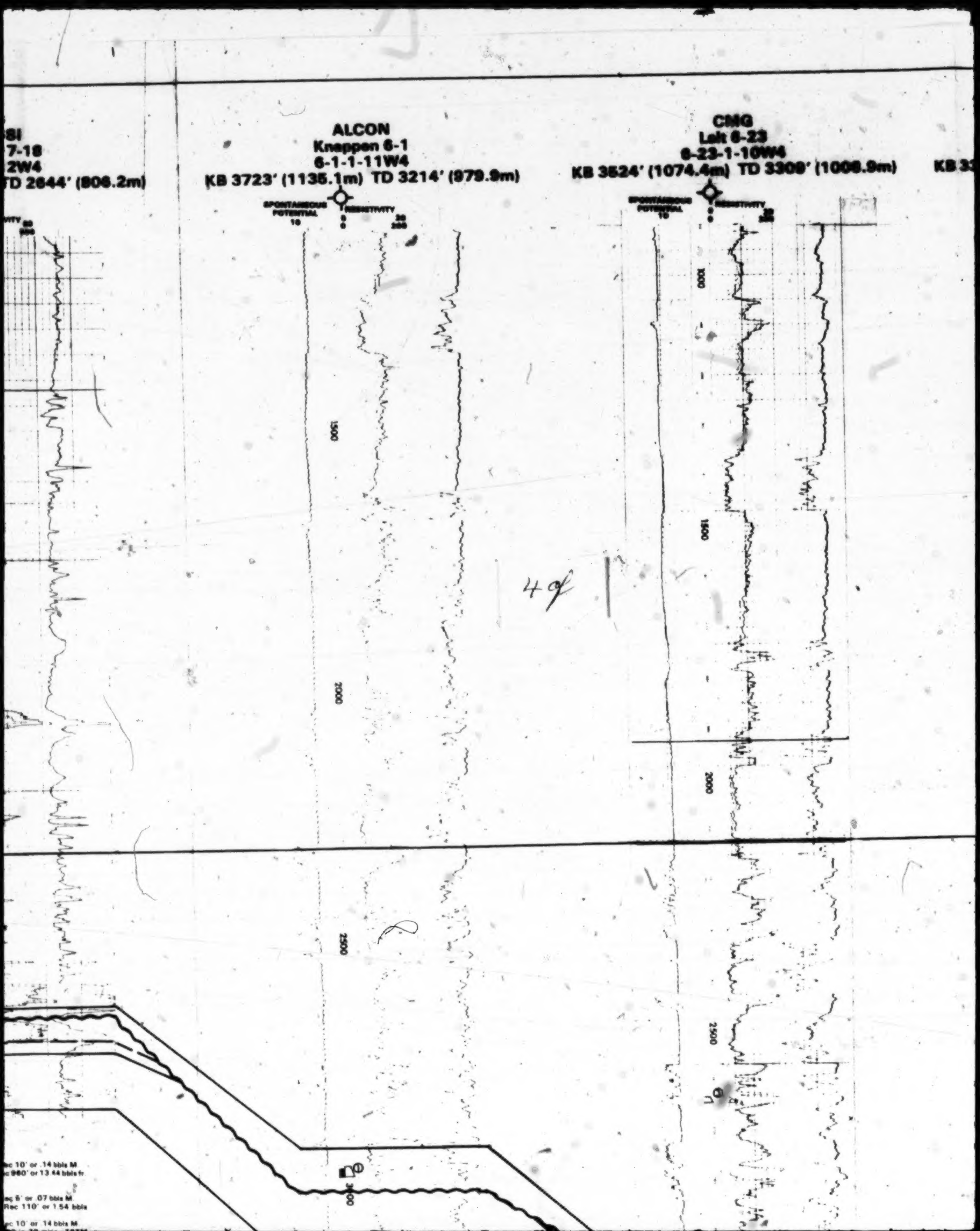
No PERFS

1. 1430-60 VO 1 hr. SI 30/30 mins. Rec 520' fr W. FP 240 HP 704 SIP 352-352

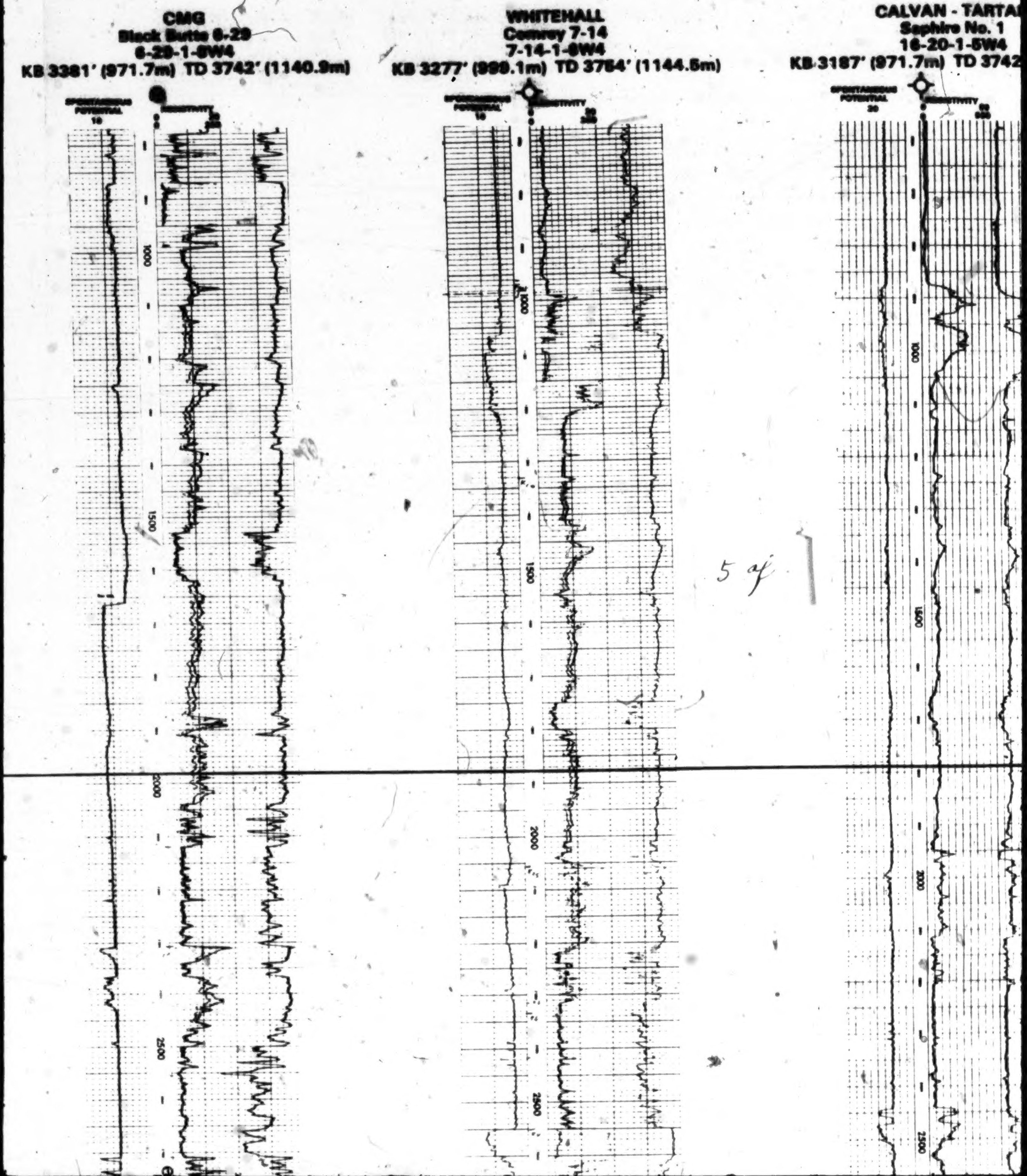
No CORES

No PERFS

1. 1783-1820 VO 30 Rec 10' or .14 bbls M.
2. 1813-1850 VO 60 Rec 960' or 13.44 bbls fr. W.
3. 2013-2040 Misrun
4. 2272-2294 VO 30 Rec 5' or .07 bbls M.
5. 2452-2472 VO 60 Rec 110' or 1.54 bbls mdy W.
6. 2541-2571 VO 10 Rec 10' or .14 bbls M.
7. 2591-2646 VO 60 GTS in 30 mins. TSTM Rec 2225' or 31.15 bbls sl. OCW.


SI
7-18
2W4
TD 2644' (806.2m)
ALCON
Knappen 6-1
6-1-1-11W4
KB 3723' (1135.1m) TD 3214' (979.9m)
SPONTANEOUS POTENTIAL
10
RESISTIVITY
0
0
20
200
1500
2000
2500
3000
CMG
Lalt 6-23
6-23-1-10W4
KB 3524' (1074.4m) TD 3309' (1008.9m)
SPONTANEOUS POTENTIAL
10
RESISTIVITY
0
0
20
200
1000
1500
2000
2500
KB 3
ec 10' or .14 bbls M
c 960' or 13.44 bbls fr
ec 6' or .07 bbls M
Rec 110' or 1.54 bbls
ec 10' or .14 bbls M

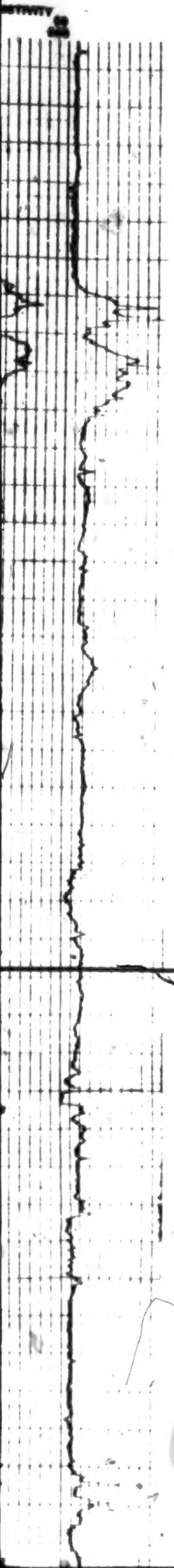
4 of

CMG
Black Butte 6-29
6-29-1-6W4
KB 3381' (971.7m) TD 3742' (1140.9m)
SPONTANEOUS POTENTIAL
10
RESISTIVITY
0
20
200
1000
1500
2000
2500
WHITEHALL
Comrey 7-14
7-14-1-6W4
KB 3277' (999.1m) TD 3754' (1144.5m)
SPONTANEOUS POTENTIAL
10
RESISTIVITY
0
20
200
1000
1500
2000
2500
CALVAN - TARTA
Saphire No. 1
16-20-1-5W4
KB 3187' (971.7m) TD 3742
SPONTANEOUS POTENTIAL
20
RESISTIVITY
0
20
200
1000
1500
2000
2500

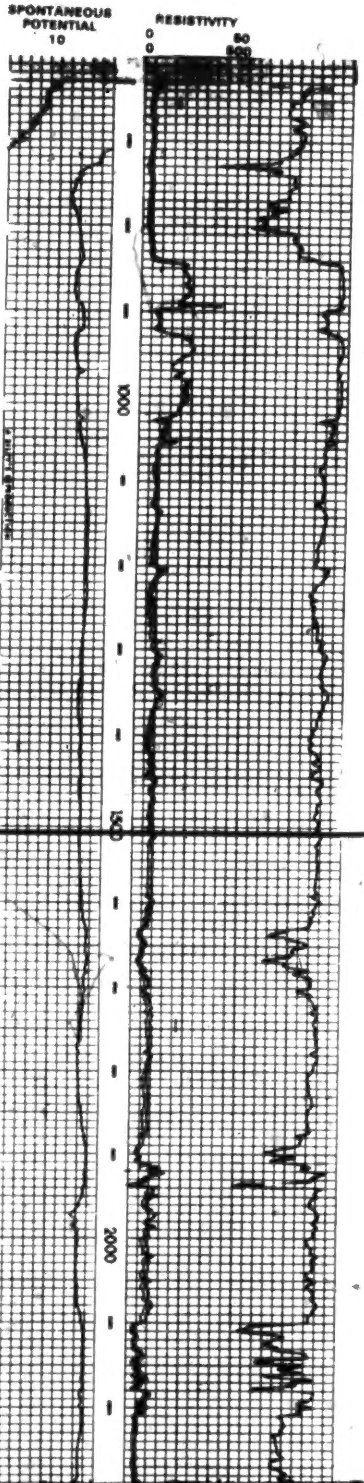
5 of

1

- TARTAN
ire No. 1
0-1-5W4
) TD 3742' (1140.9m)

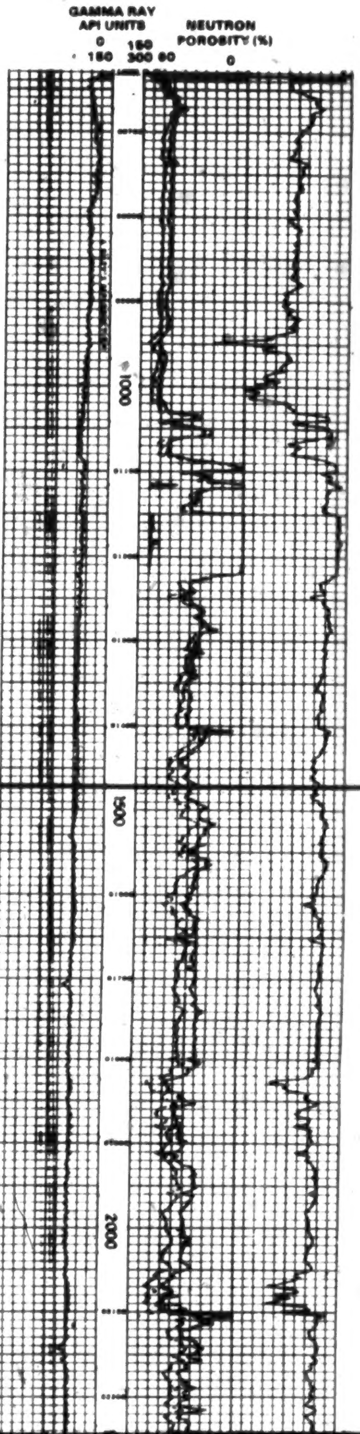


PAC. - AMOCO
One Four 1-4
6-16-1-4W4
KB 2917' (889.4m) TD 3671' (1119.2m)



CMG
Bain 6-2
6-2-1-3W4
KB 2875' (876.6m) TD 3964' (1208.5m)

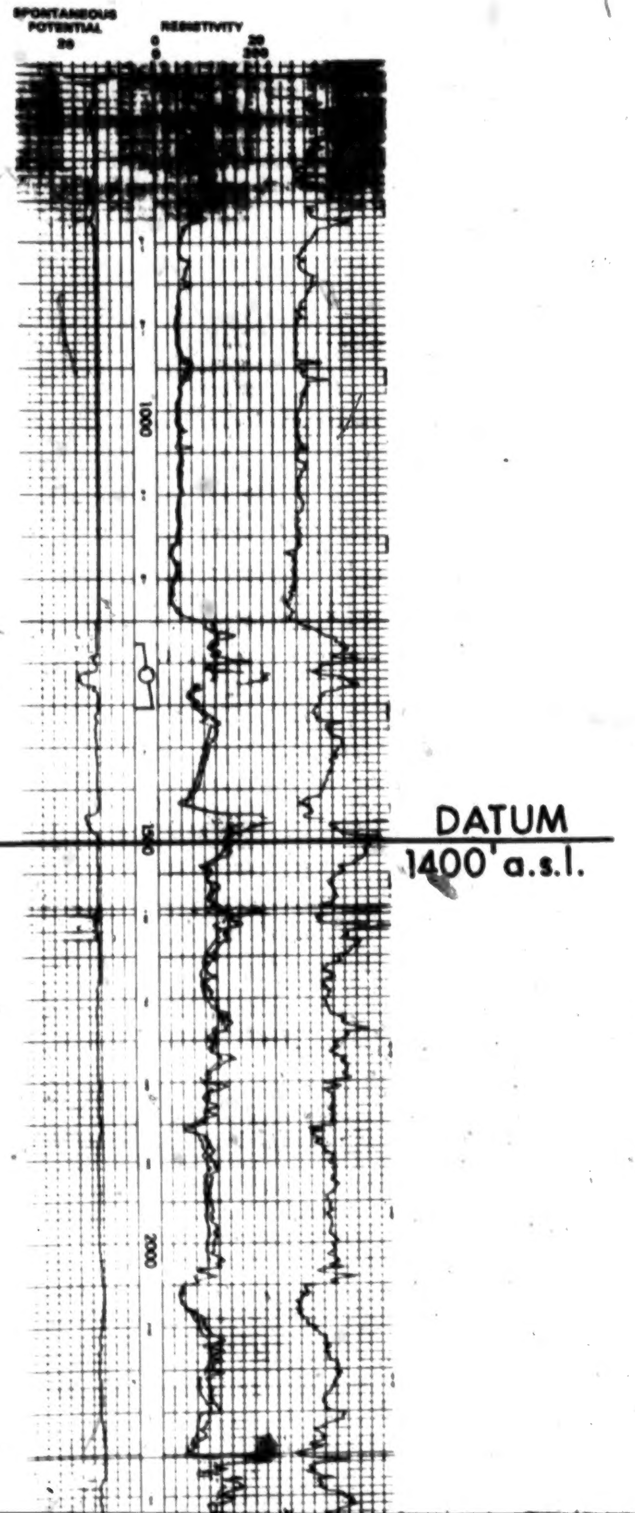
6 af



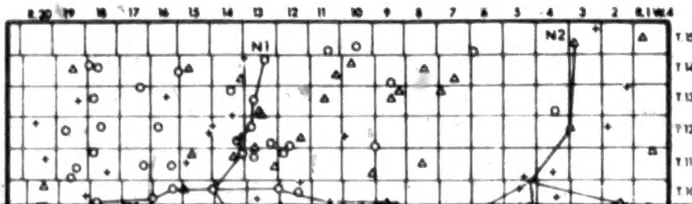
KB

E2S

B.A. - H.B.
Sage Creek 10-8
10-8-2-1W4
KB 2911' (887.6m) TD 3948' (1203.7m)



7 af


R.20
19
18
17
16
15
14
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12
11
10
9
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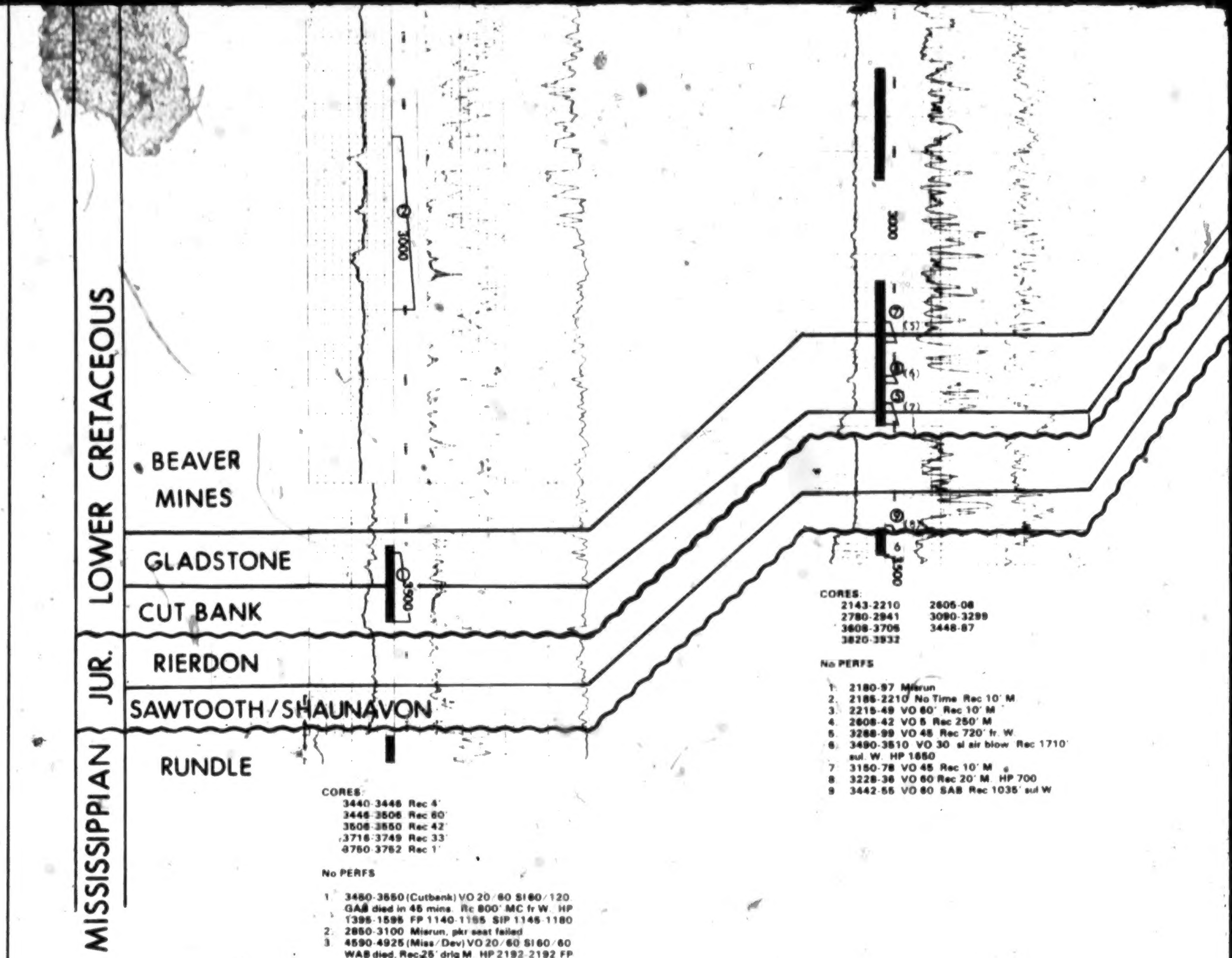
6
5
4
3
2
R.1 W.4
T15
T14
T13
T12
T11
T10
N1
N2


LOWER CRETACEOUS
BEAVER MINES
GLADSTONE
CUT BANK
JUR.
RIERDON
SAWTOOTH/SHAUNAVON
MISSISSIPPIAN
RUNDLE
3000
3500
3000
3500
6

CORES:
3440-3446 Rec 4'
3446-3506 Rec 60'
3506-3550 Rec 42'
3716-3749 Rec 33'
3750-3752 Rec 1'

No PERFS

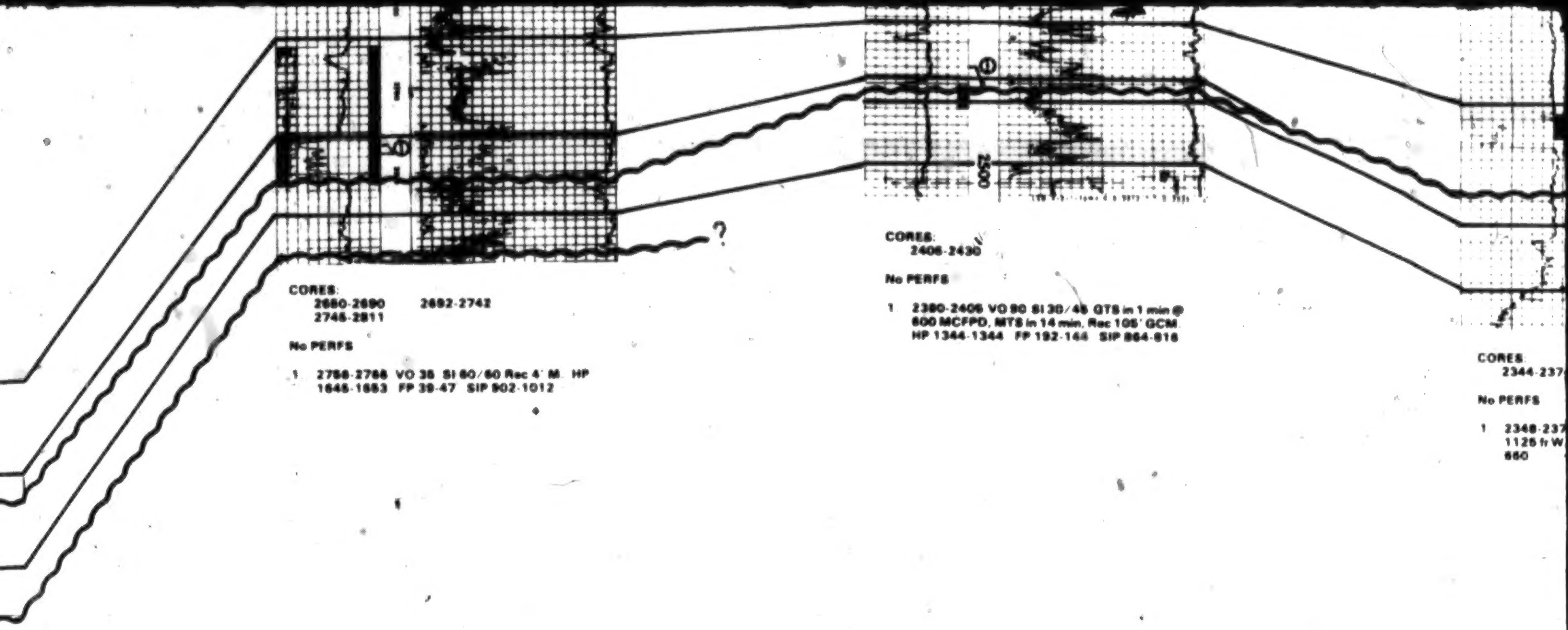
1. 3460-3550 (Cutbank) VO 20/60 SI 60/120 GAS died in 45 mins. Rc 800' MC fr W. HP 1395-1595 FP 1140-1155 SIP 1145-1180
2. 2850-3100 Misrun, pkr seat failed
3. 4590-4925 (Miss/Dev) VO 20/60 SI 60/60 WAB died, Rec 25' drlg M. HP 2192-2192 FP 61-51 SIP 128-67

CORES:
2143-2210 2606-08
2780-2941 3090-3299
3608-3706 3448-87
3820-3932

No PERFS

1. 2180-97 Misrun
2. 2186-2210 No Time Rec 10' M
3. 2215-49 VO 60' Rec 10' M
4. 2608-42 VO 5 Rec 250' M
5. 3268-99 VO 45 Rec 720' fr. W
6. 3490-3510 VO 30 sl air blow Rec 1710' sul. W. HP 1650
7. 3150-78 VO 45 Rec 10' M
8. 3228-36 VO 60 Rec 20' M. HP 700
9. 3442-55 VO 60 SAB Rec 1035' sul W

8 of



CORES:
2680-2690 2692-2742
2746-2811

No PERFS

1. 2758-2768 VO 35 SI 60/60 Rec 4' M. HP
1646-1653 FP 39-47 SIP 902-1012

CORES:
2406-2430

No PERFS

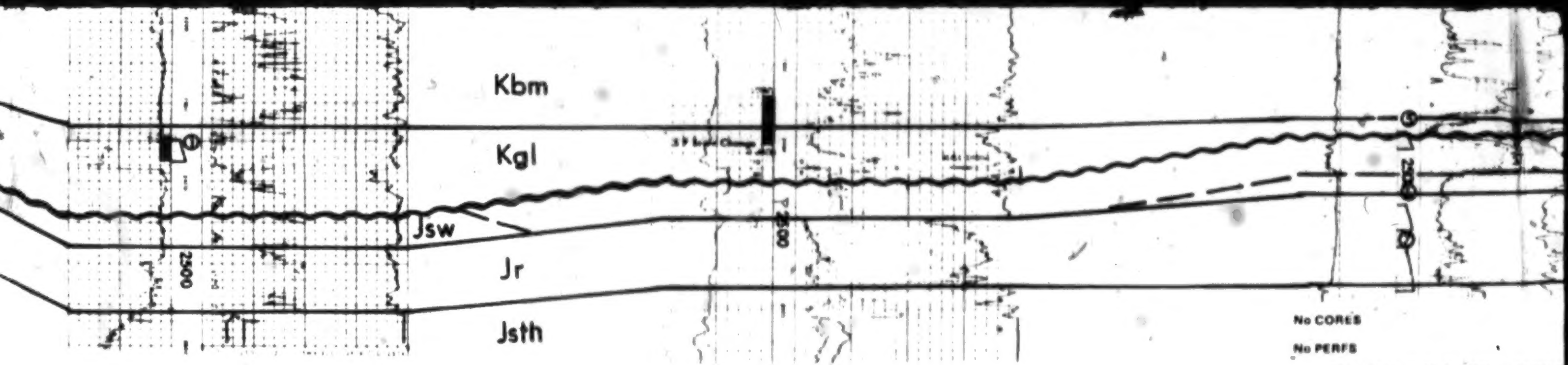
1. 2380-2406 VO 90 SI 30/45 GTS in 1 min @
600 MCFPD, MTS in 14 min, Rec 105' GCM.
HP 1344-1344 FP 192-144 SIP 864-816

CORES:
2344-237

No PERFS

1 2348-237
1125 fr W
660

9 of



CORES
2344-2374

No PERFS

1 2348-2376 VO 60 SI 15/15 mins. Rec 1125 fr W. HP 1306-1306 FP 200-470 FSIP 860

CORES
2340-2400

No PERFS

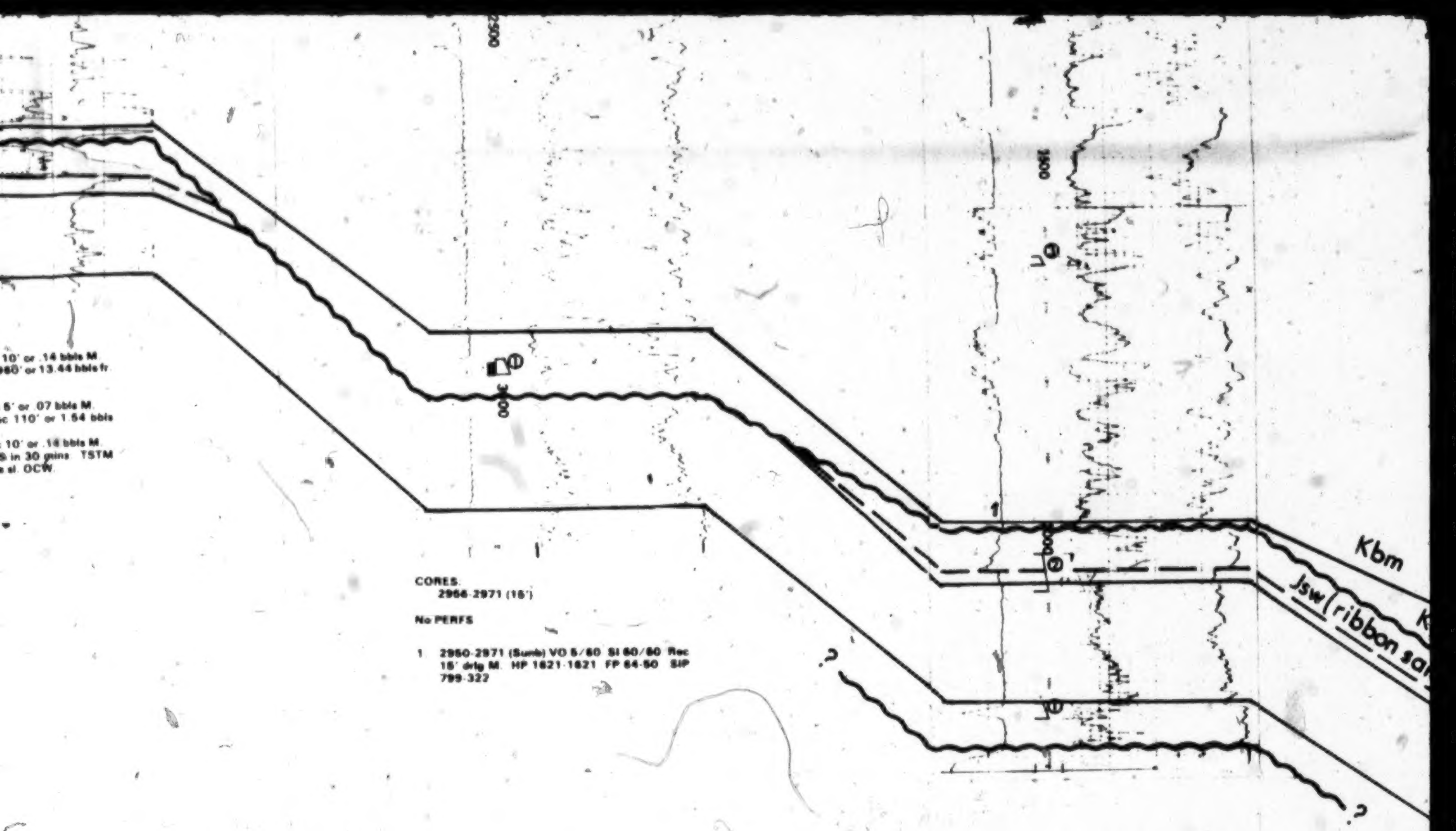
1 =1430-60 VO 1 hr. SI 30/30 mins. Rec 520' fr W. FP 240 HP 704 SIP 352-352

No CORES

No PERFS

1 1783-1820 VO 30 Rec 10' or .14 bbls
2 1813-1850 VO 60 Rec 960' or 13.44 bbl
W.
3 2013-2040 Misrun
4 2272-2294 VO 30 Rec 5' or .07 bbls M
5 2452-2472 VO 60 Rec 110' or 1.54
mdy W.
6 2541-2571 VO 10 Rec 10' or .14 bbls
7 2591-2645 VO 60 GTS in 30 mins. TS
Rec 2226' or 31.15 bbls of OCW.

10 of



10' or .14 bbls M.
960' or 13.44 bbls fr.

5' or .07 bbls M.
c 110' or 1.54 bbls

10' or .14 bbls M.
S in 30 mins. TSTM
s sl. OCW.

CORES:
2966-2971 (15')

No PERFS

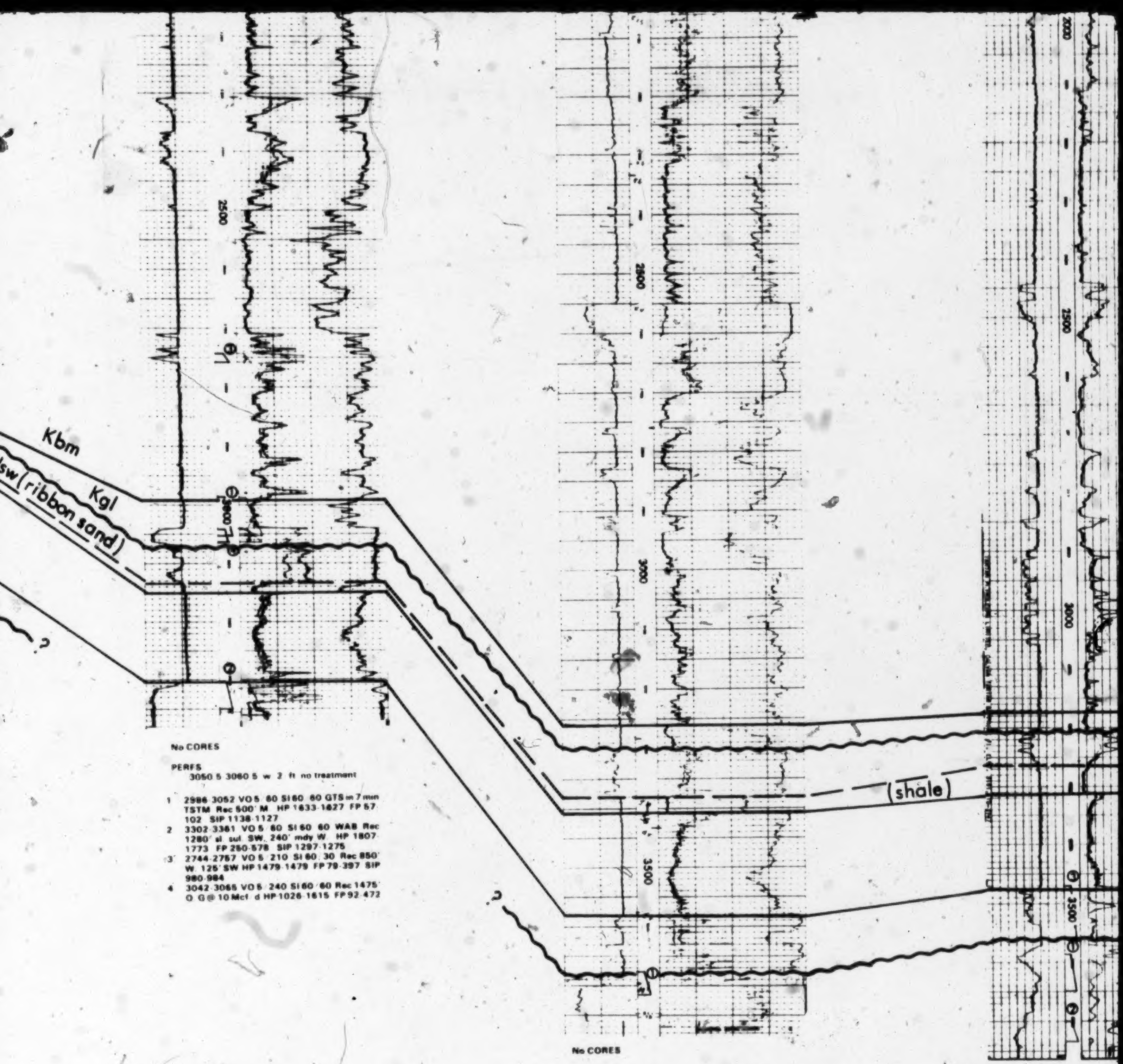
1 2960-2971 (Sumb) VO 5/60 SI 60/60 Rec 15' drlg M. HP 1621-1621 FP 64-50 SIP 799-322

No CORES

No PERFS

1 3228-50 (Sawtooth) VO 5 46 SI 60 30 v/AB Reset Rec 5' M. HP 1713-1720 FP 22-21 SIP 162-28
2 3030-80 (Blairmore) VO 5 30 SI 60 30 Rec 60 M. HP 1653-1630 FP 50-79 SIP 1061-957
3 2633-44 (Bel Colo) VO 5/60 SI 60/60 Rec 940 W. HP 1424-1407 FP 141-409 SIP 899-875

Fk ofw


Kbm
Kgl
sw (ribbon sand)
?
2500
3000
3500
2500
3000
3500
2000
2500
3000
3500
(shale)
?

No CORES

PERFS
3050.5-3060.5 w 2 ft no treatment

1 2986-3052 VO 5 60 SI 60 60 GTS in 7 min TSTM Rec 500' M HP 1633-1627 FP 57-102 SIP 1138-1127
2 3302-3361 VO 5 60 SI 60 60 WAB Rec 1280' sl sul SW, 240' mdy W HP 1807-1773 FP 250-578 SIP 1297-1275
3 2744-2767 VO 5 210 SI 60 30 Rec 850' W, 125' SW HP 1479-1479 FP 79-397 SIP 980-984
4 3042-3065 VO 5 240 SI 60 60 Rec 1475' O G @ 10 Mcf d HP 1026-1615 FP 92-472

No CORES

No PERFS

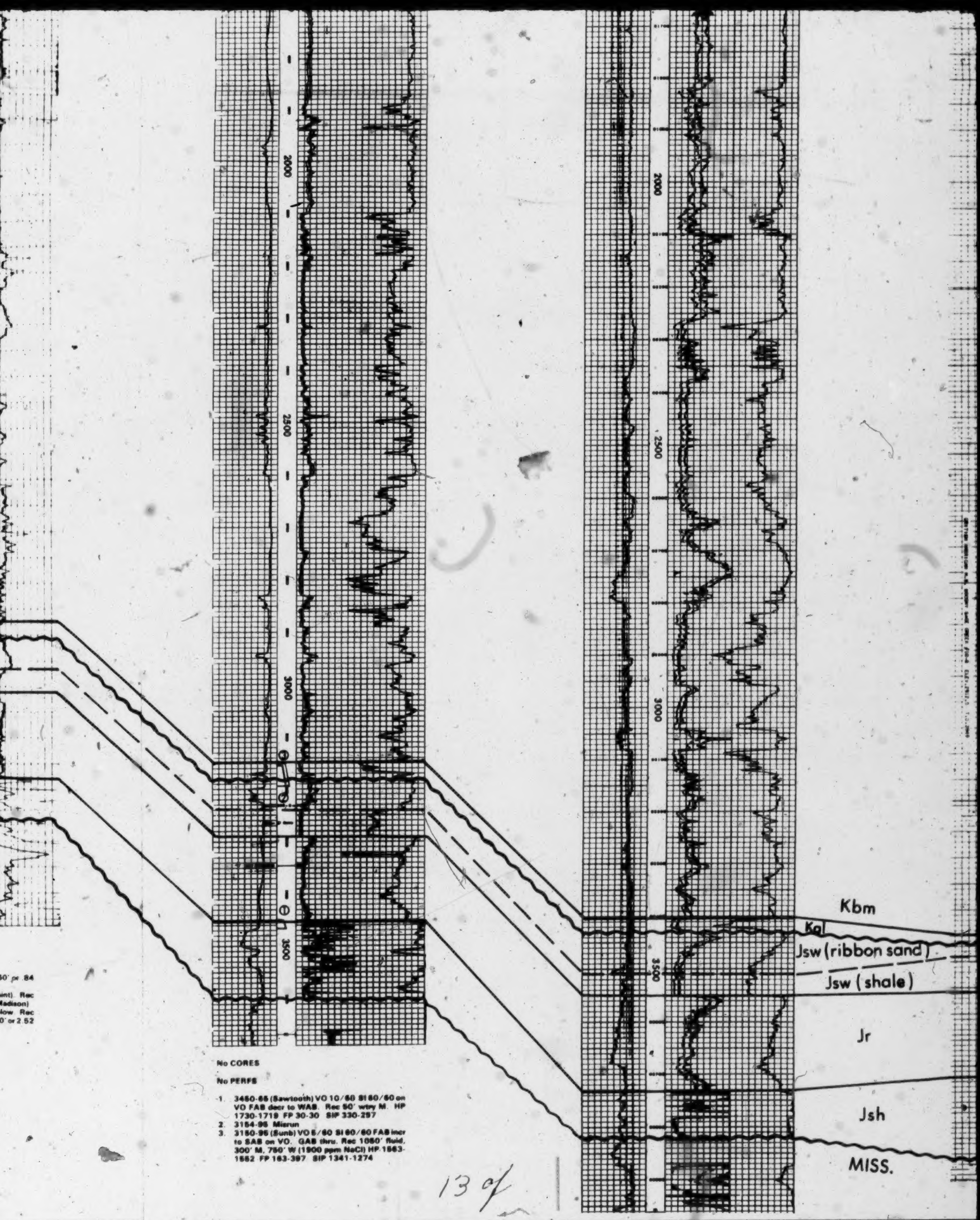
1 3676-3714 (Rundle) Misrun

No CORES

No PERFS

1. 3585-3650' VO 1 hr
bbls M w/O [illegible].
2. 3700-43' VO 1 hr. 2
180' or 2.52 bbls. M.
3. 3470-3546' VO 55
3190' or 44.66 bbls
bbls M.

12 of



2000
2500
3000
3500
2000
2500
3000
3500
Kbm
Kal
Jsw (ribbon sand)
Jsw (shale)
Jr
Jsh
MISS.

0' pr .84

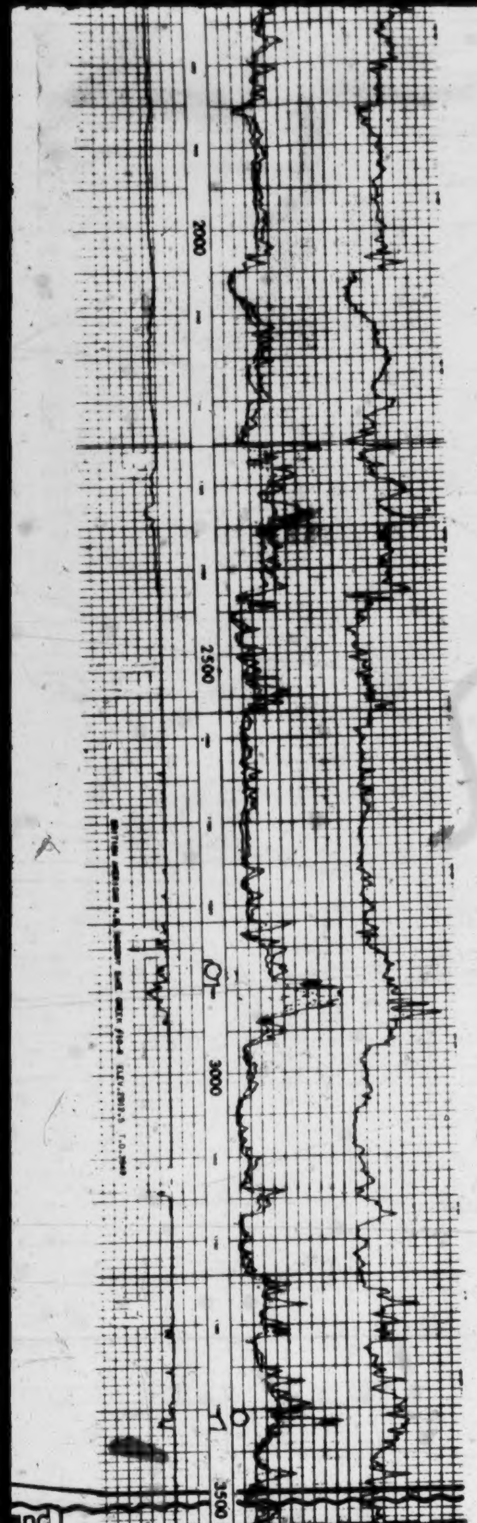
int). Rec
Madison)
low Rec
0' or 2.52

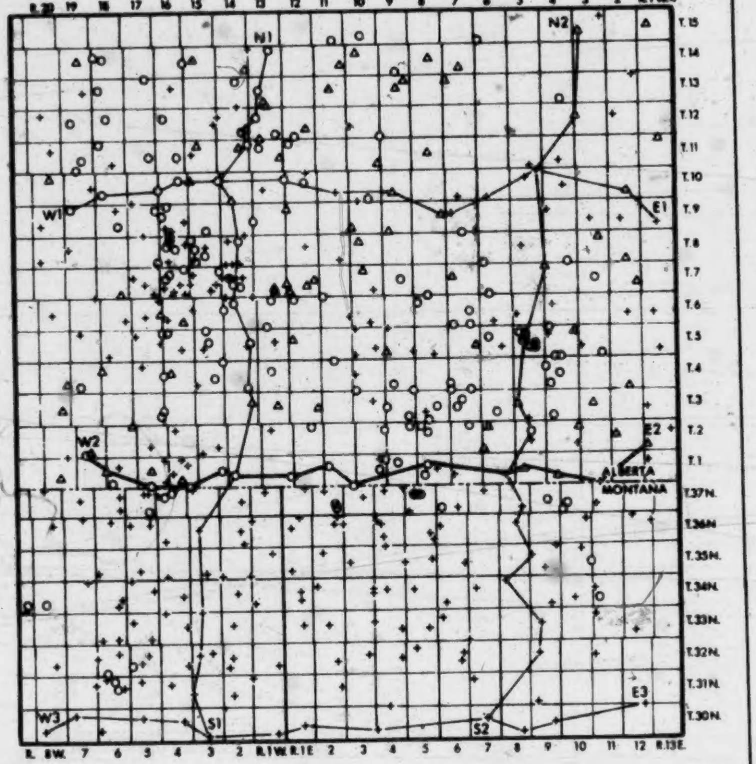
No CORES

No PERFS

1. 3460-65 (Sawtooth) VO 10/60 SI 60/60 on VO FAB decr to WAB. Rec 50' wtry M. HP 1730-1719 FP 30-30 SIP 330-257
2. 3154-96 Misrun
3. 3150-95 (Sunb) VO 5/60 SI 60/60 FAB incr to SAB on VO. GAB thru. Rec 1050' fluid, 300' M, 750' W (1900 ppm NaCl) HP 1563-1562 FP 163-397 SIP 1341-1274

13 of




R.20
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R.1W.4
T.15
T.14
T.13
T.12
T.11
T.10
T.9
T.8
T.7
T.6
T.5
T.4
T.3
T.2
T.1
T.37N.
T.36N.
T.35N.
T.34N.
T.33N.
T.32N.
T.31N.
T.30N.
N1
N2
W1
E1
W2
E2
ALBERTA
MONTANA
W3
S1
S2
E3
R. 8W.
7
6
5
4
3
2
R.1W.
R.1E
2
3
4
5
6
7
8
9
10
11
12
R.13E.

CROSS SECTION LOCATION MAP
SOUTHEASTERN ALBERTA-NORTHERN MONTANA

0 5 10 15 20 25 30
MILES (Approx.)

CORES:
3782-3830

PERFS:
3771'-80' w/8/ft.

2. 2866-2896 VO 30 min Shut in 15 min. Rec 2100' or 29.40 bbls. MCSW. FP 910 SIP 990 HP 1680
3. 3409-3422 VO 25 min. Rec 30' or .42 bbls M.
4. 3771-3784 VO 1 hr. Shut in 10 mins. GTS in 2½ mins. @ 2.4 MMCFPD Rec 1' M. FP 460 SIP 1730 HP 2190
5. 3780-3792 VO 30 mins Shut in 10 mins. GTS 1 min. @ 4.2 MMCFPD Rec 13' or .18 bbls M.
6. 3792-3799 VO 40 mins Shut in 15 min. Rec 420' or 5.88 bbls heavily O ft mdy sli slty W. Hp 2200 FP 325-730 SIP 1675

14 of 14

FIGURE 14

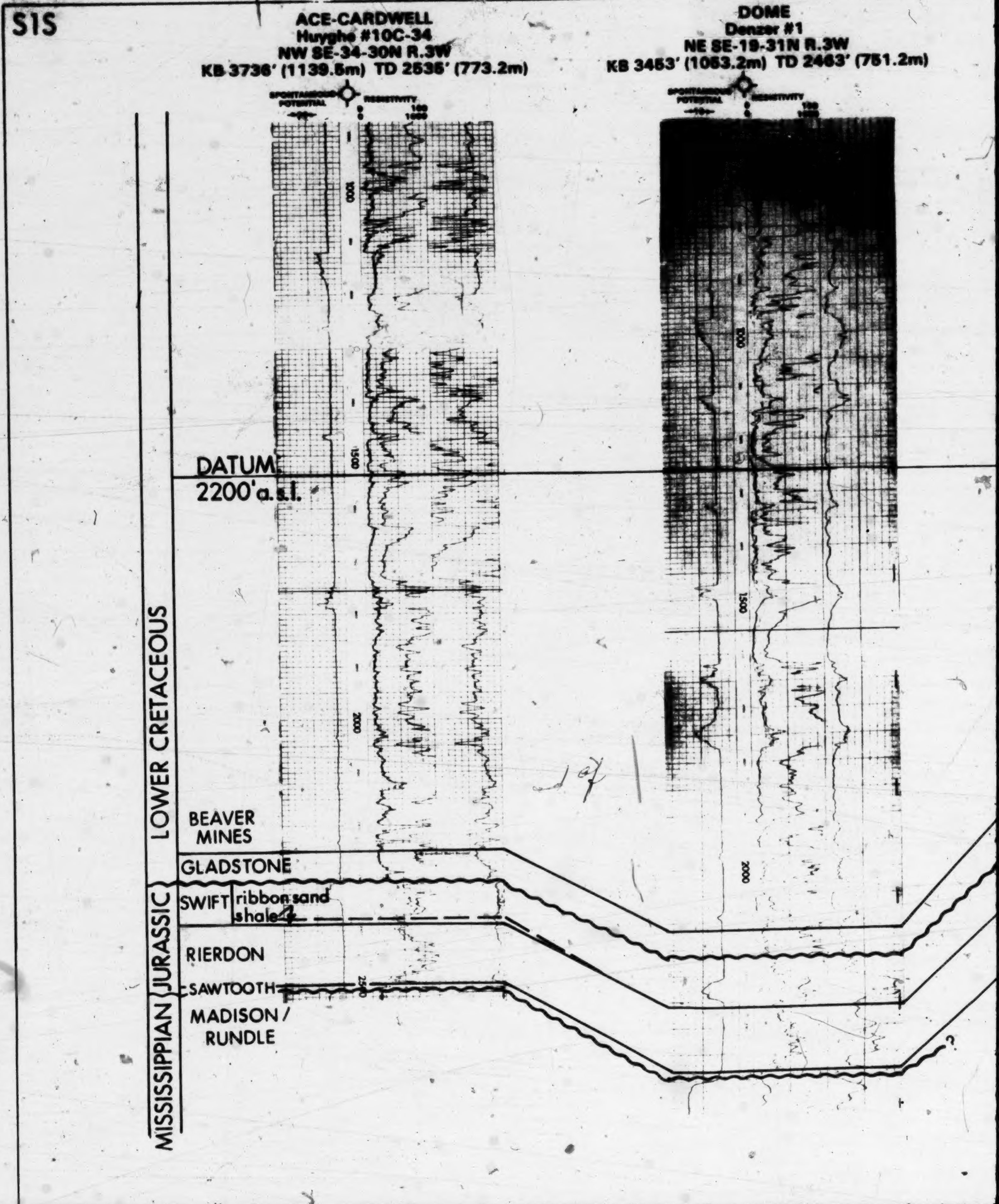
STRUCTURAL CROSS-SECTION
W2S-E2S

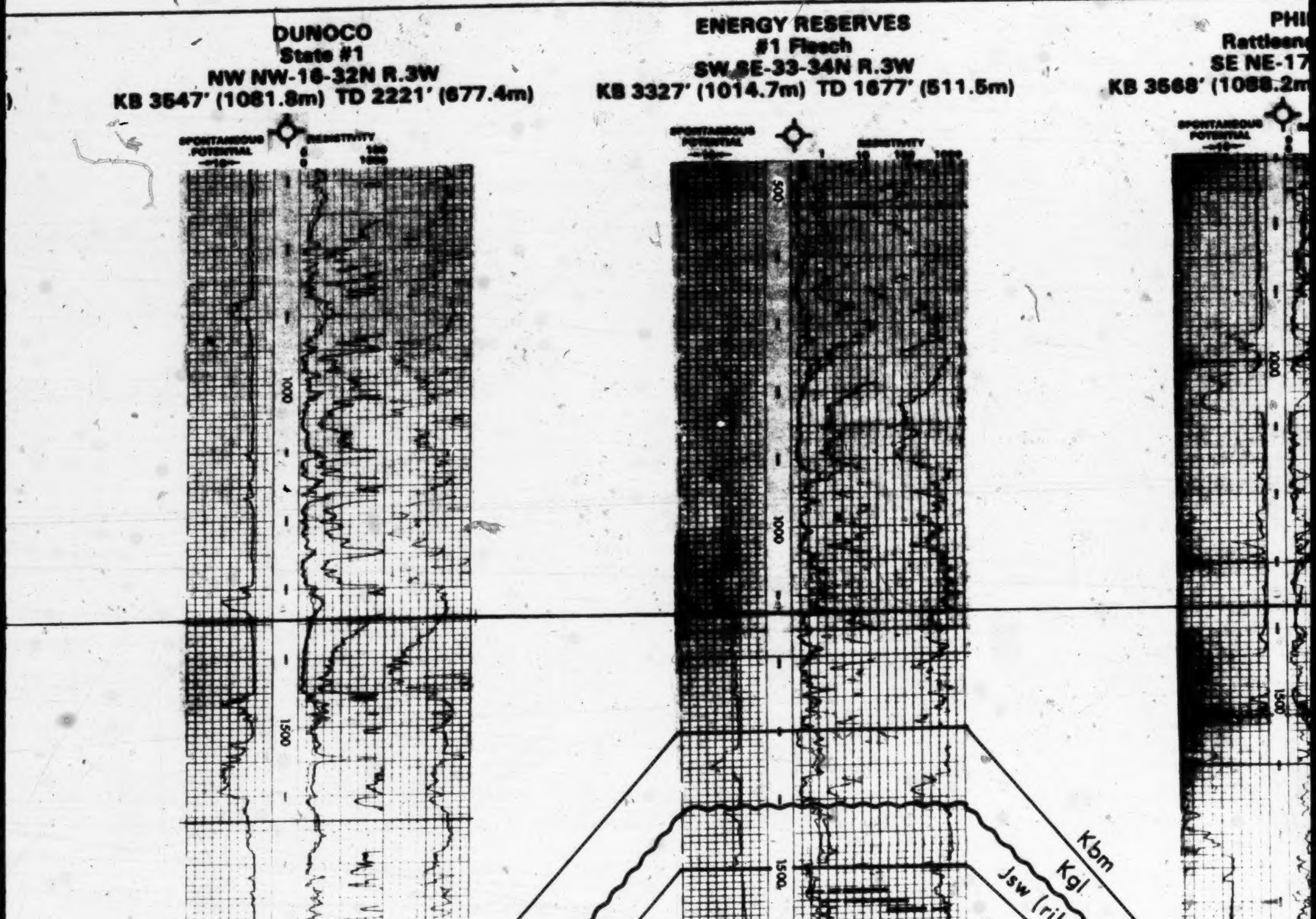
DATUM: 1400 feet above sea level.

B. Hayes
University of Alberta
1981

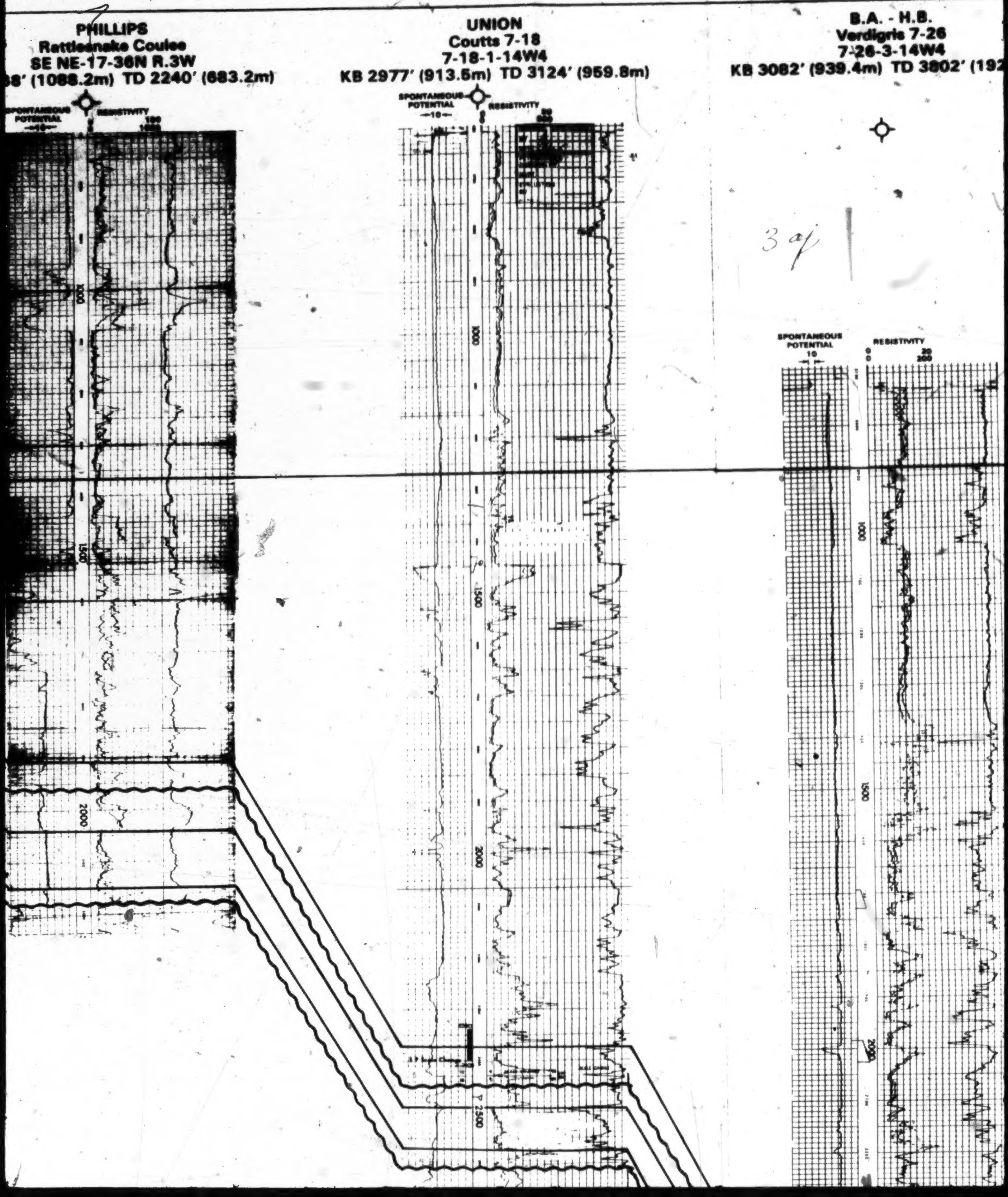
VERTICAL SCALE: 1" = 200'

S1S

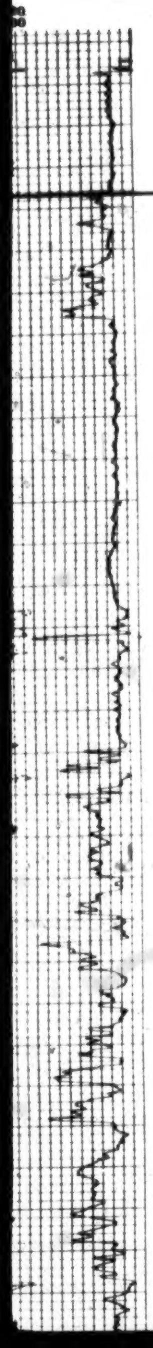

ACE-CARDWELL
Huyghe #10C-34
NW SE-34-30N R.3W
KB 3736' (1139.5m) TD 2535' (773.2m)
DOME
Denzer #1
NE SE-19-31N R.3W
KB 3453' (1053.2m) TD 2463' (751.2m)
SPONTANEOUS POTENTIAL
RESISTIVITY
1000
1500
2000
2500
DATUM
2200' a.s.l.
LOWER CRETACEOUS
JURASSIC
MISSISSIPPIAN
BEAVER MINES
GLADSTONE
SWIFT
ribbon sand
shale
RIERDON
SAWTOOTH
MADISON / RUNDLE
?


DUNOCO
State #1
NW NW-16-32N R.3W
KB 3547' (1081.8m) TD 2221' (677.4m)
SPONTANEOUS POTENTIAL
RESISTIVITY
1000
1500
2000
ENERGY RESERVES
#1 Flesch
SW SE-33-34N R.3W
KB 3327' (1014.7m) TD 1677' (511.5m)
SPONTANEOUS POTENTIAL
RESISTIVITY
1
10
100
1000
500
1000
1500
PHI
Rattlesn
SE NE-17
KB 3568' (1088.2m
SPONTANEOUS POTENTIAL
1000
1500
2000
Kbm
Kgl
Jsw (ribbon sand)
Jr
Jsth
MISS.
?
?

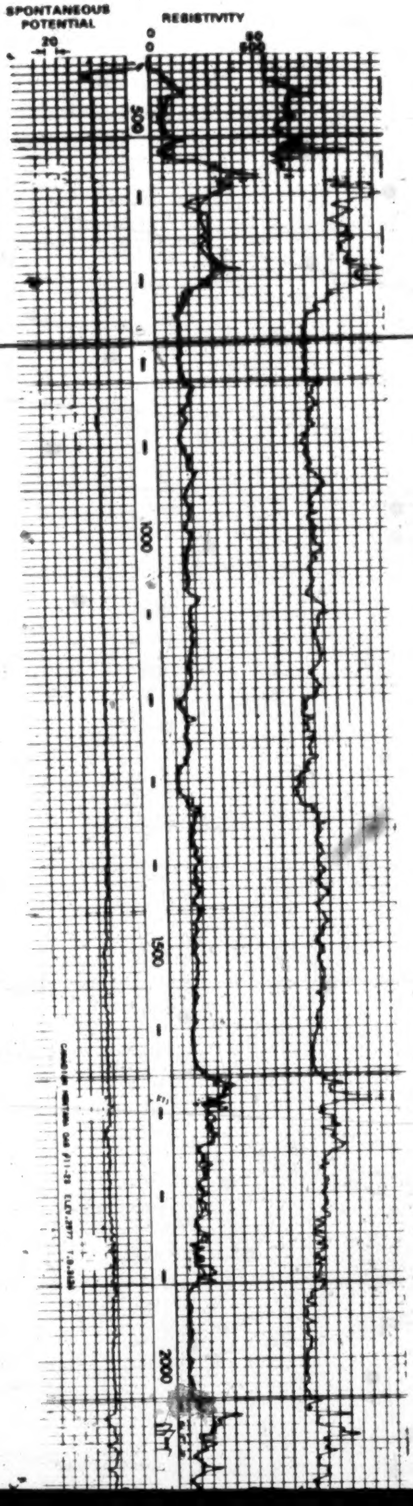
2 of


PHILLIPS
Rattlesnake Coulee
SE NE-17-36N R.3W
38' (1088.2m) TD 2240' (683.2m)
SPONTANEOUS POTENTIAL
RESISTIVITY
1000
1500
2000
UNION
Coutts 7-18
7-18-1-14W4
KB 2977' (913.5m) TD 3124' (959.8m)
SPONTANEOUS POTENTIAL
RESISTIVITY
1000
1500
2000
2500
B.A. - H.B.
Verdigris 7-26
7-26-3-14W4
KB 3082' (939.4m) TD 3802' (192
3 aj
SPONTANEOUS POTENTIAL
RESISTIVITY
1000
1500
2000

26
W4
802' (1928.5m)

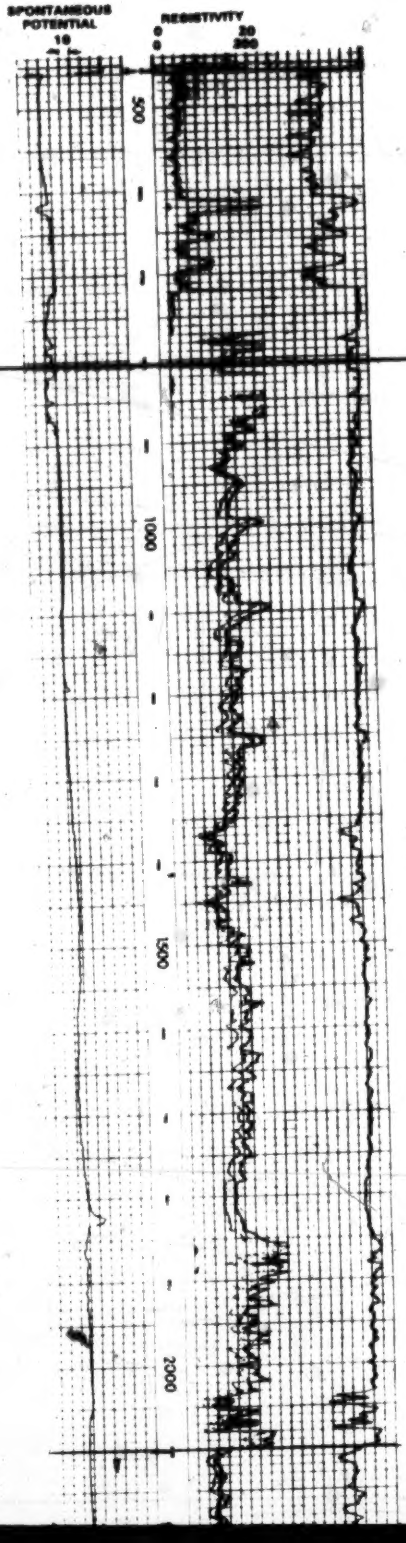


CMG
CMG 11-23
11-23-5-14W4
KB 2977' (913.5m) TD 3124' (959.8m)



4.9'

PAN AM.
Skiff 4-32
4-32-6-14W4
KB 3008' (916.8m) TD 3301' (1006.8m)



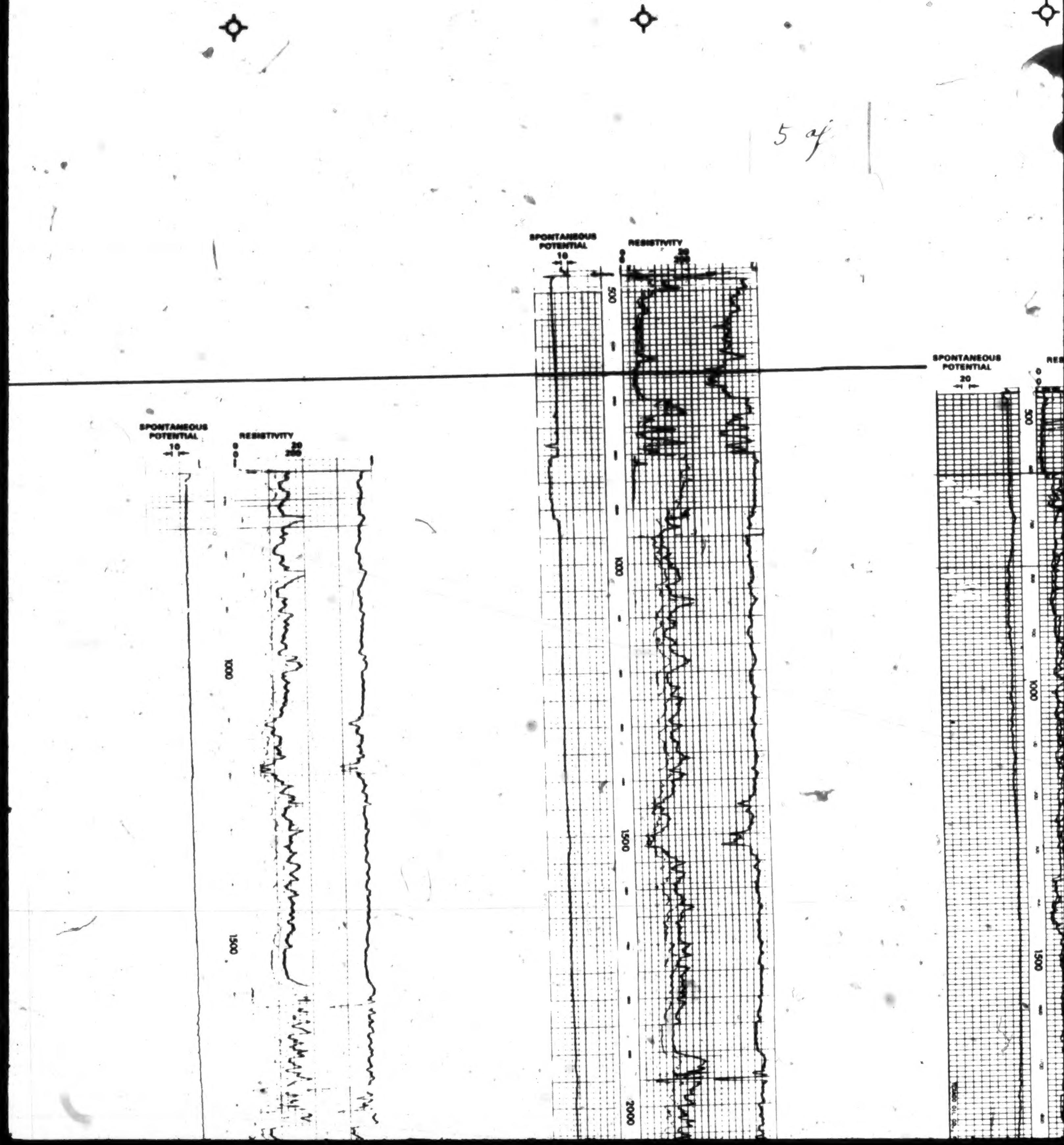
KB 2686

BRETT
Chin Coulee 15-17
15-17-7-14W4
KB 2686' (818.7m) TD 2950' (899.2m)

SUN
Chinoo 7-28
7-28-8-14W5
KB 2852' (869.3m) TD 3250' (1004.6m)

TEX
Purple Sprin
8-26-10-
KB 2613' (796.4m) T

5 af

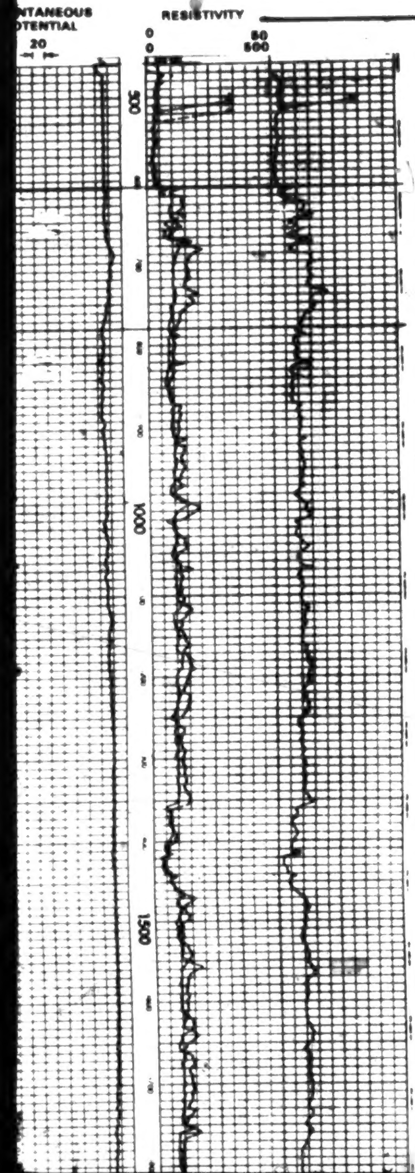


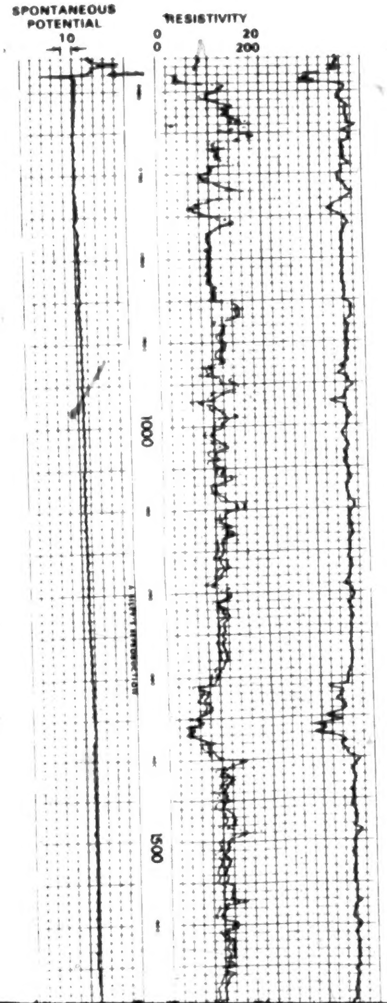
TEX.
Purple Springs #A-1
8-26-10-15W4
3' (796.4m) TD 3175' (967.7m)

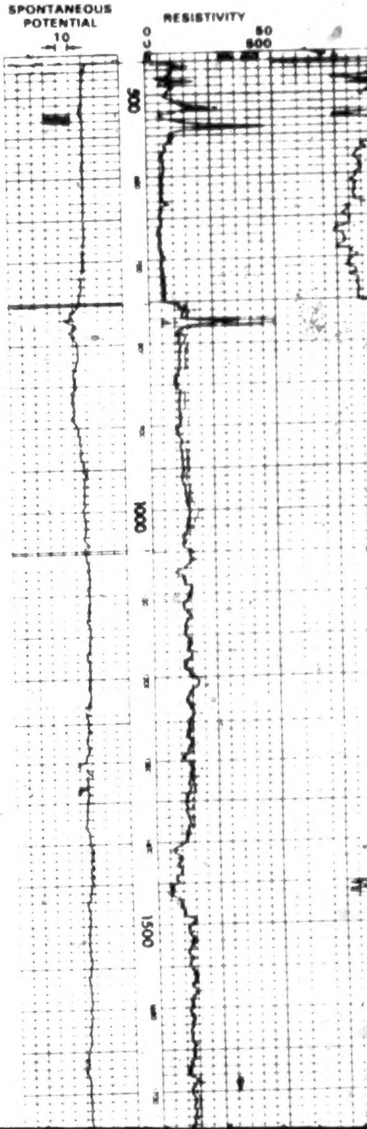
BASSET
Grand Forks 5-36
5-36-11-14W4
KB 2504' (763.2m) TD 3089' (941.5m)

B.A.
Grand Forks 7-30
7-30-12-13W4
KB 2539' (773.9m) TD 3200' (975.4m)

6 aj





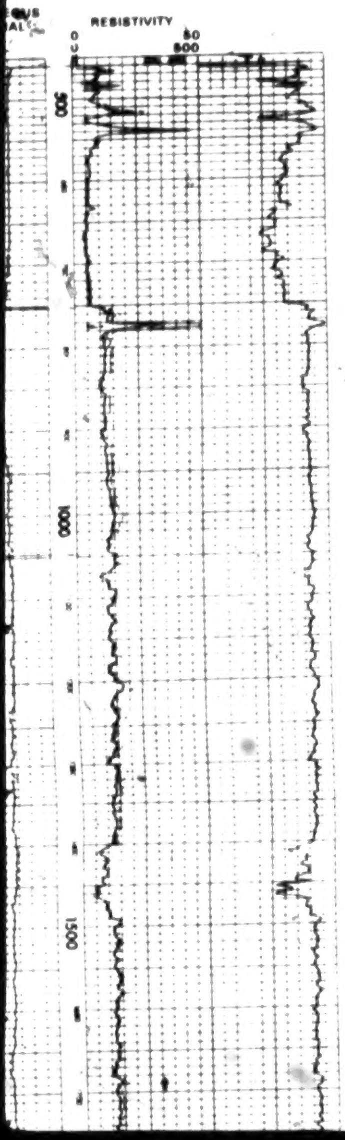


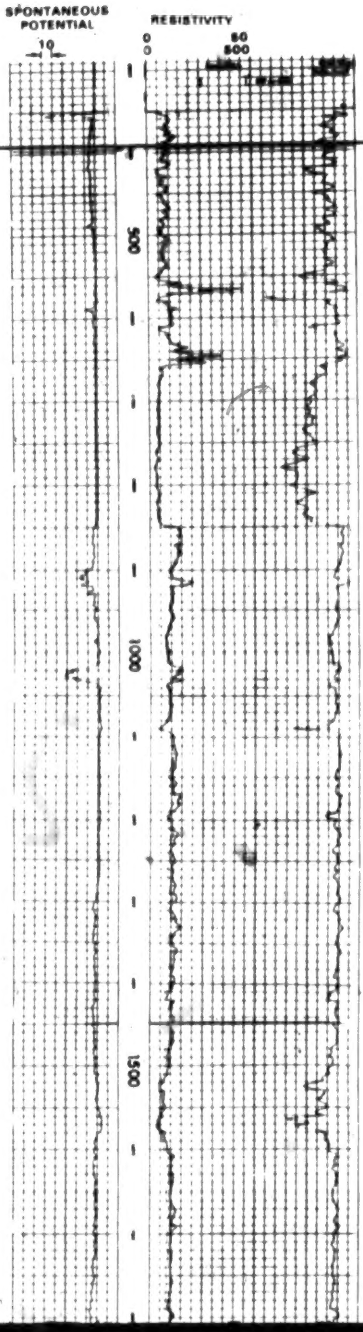
B.A.
d Forks 7-30
0-12-13W4
0m) TD 3200' (975.4m)

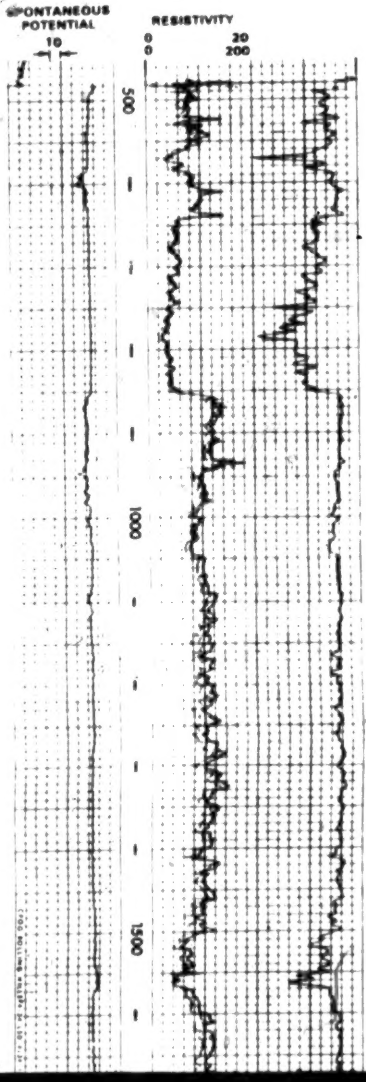
C & E
Hays 4-20
4-20-13-13W4
KB 2595' (791.0m) TD 3248' (990.3m)

CPOG
Rolling Hills 4-34
4-34-14-13W4
KB 2460' (749.8m) TD 3256' (991.8m)

DATUM:
2200' a.s.l.



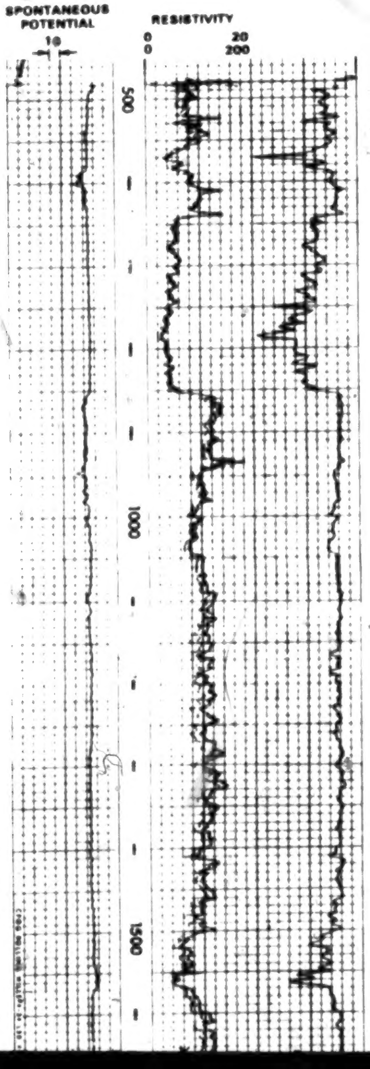


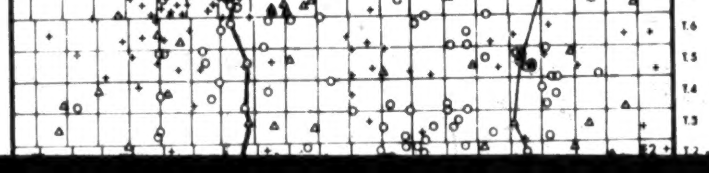


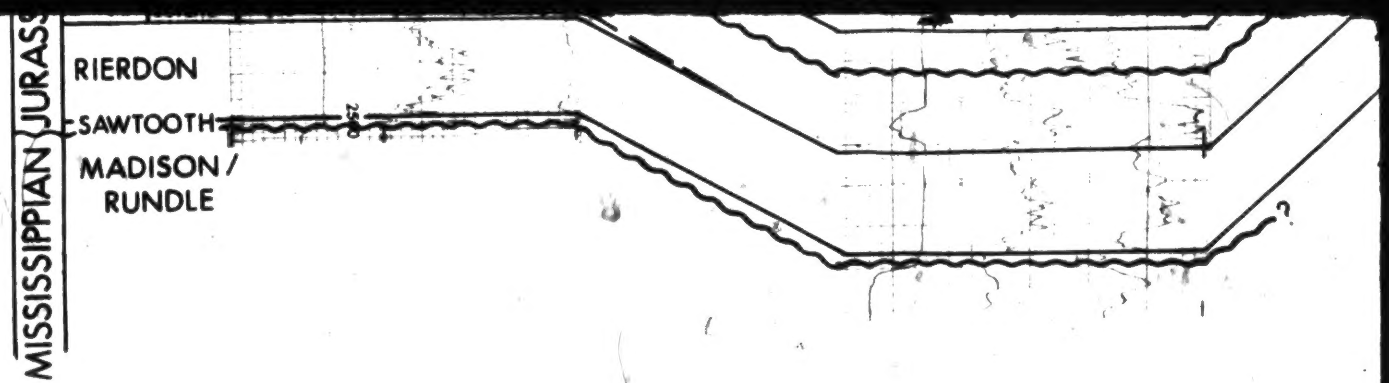
CPOG
Rolling Hills 4-34
4-34-14-13W4
KB 2460' (749.8m) TD 3256' (991.8m)

N1S

DATUM:
2200' a.s.l.

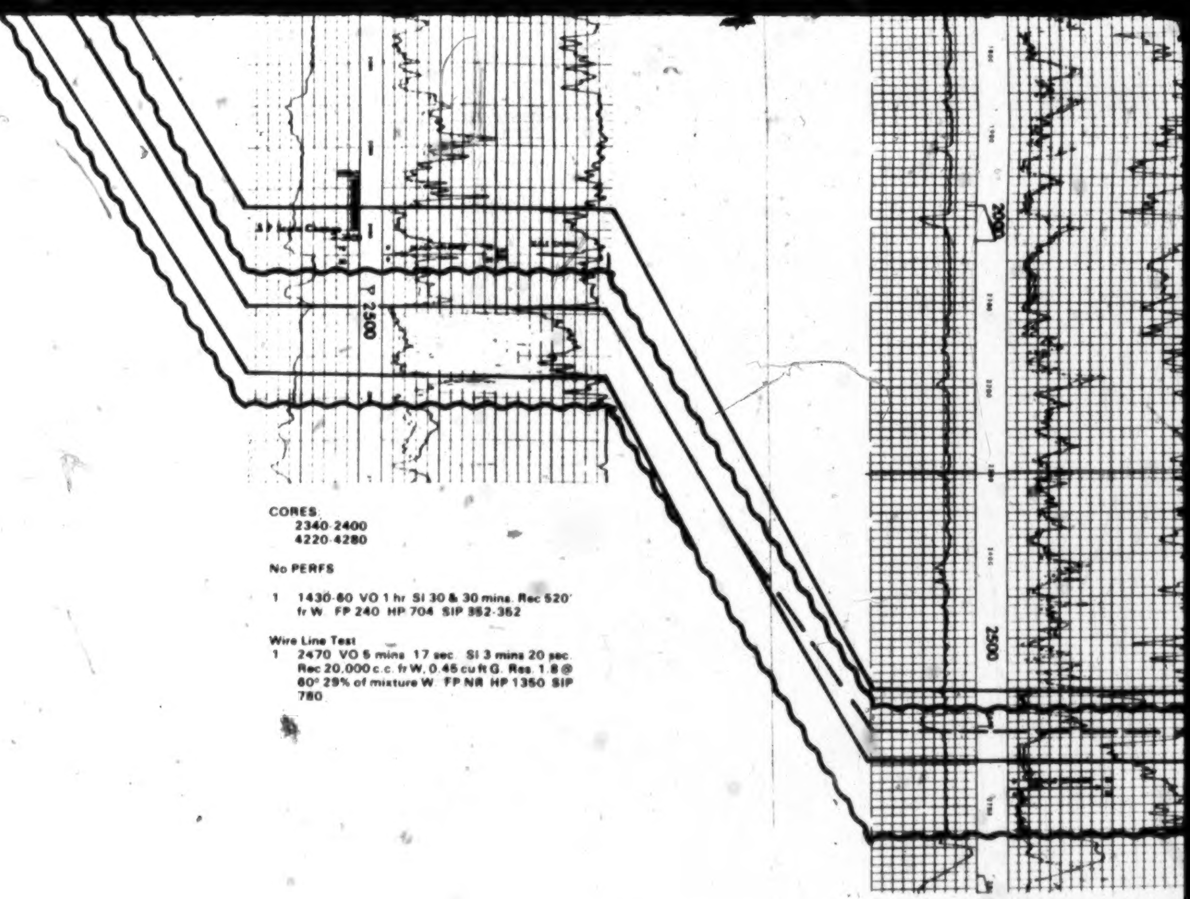



R.20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 R.1 W4
T.15
T.14
T.13
T.12
T.11
T.10
T.9
T.8
T.7
T.6
T.5
T.4
T.3
T.2
N1
N2
W1
E1
E2


JURASS
MISSISSIPPIAN
RIERDON
SAWTOOTH
MADISON /
RUNDLE
?

9 af.

10of



CORES
2340-2400
4220-4280

No PERFS

1 1430-60 VO 1 hr SI 30 & 30 mins. Rec 520' fr W. FP 240 HP 704 SIP 352-352

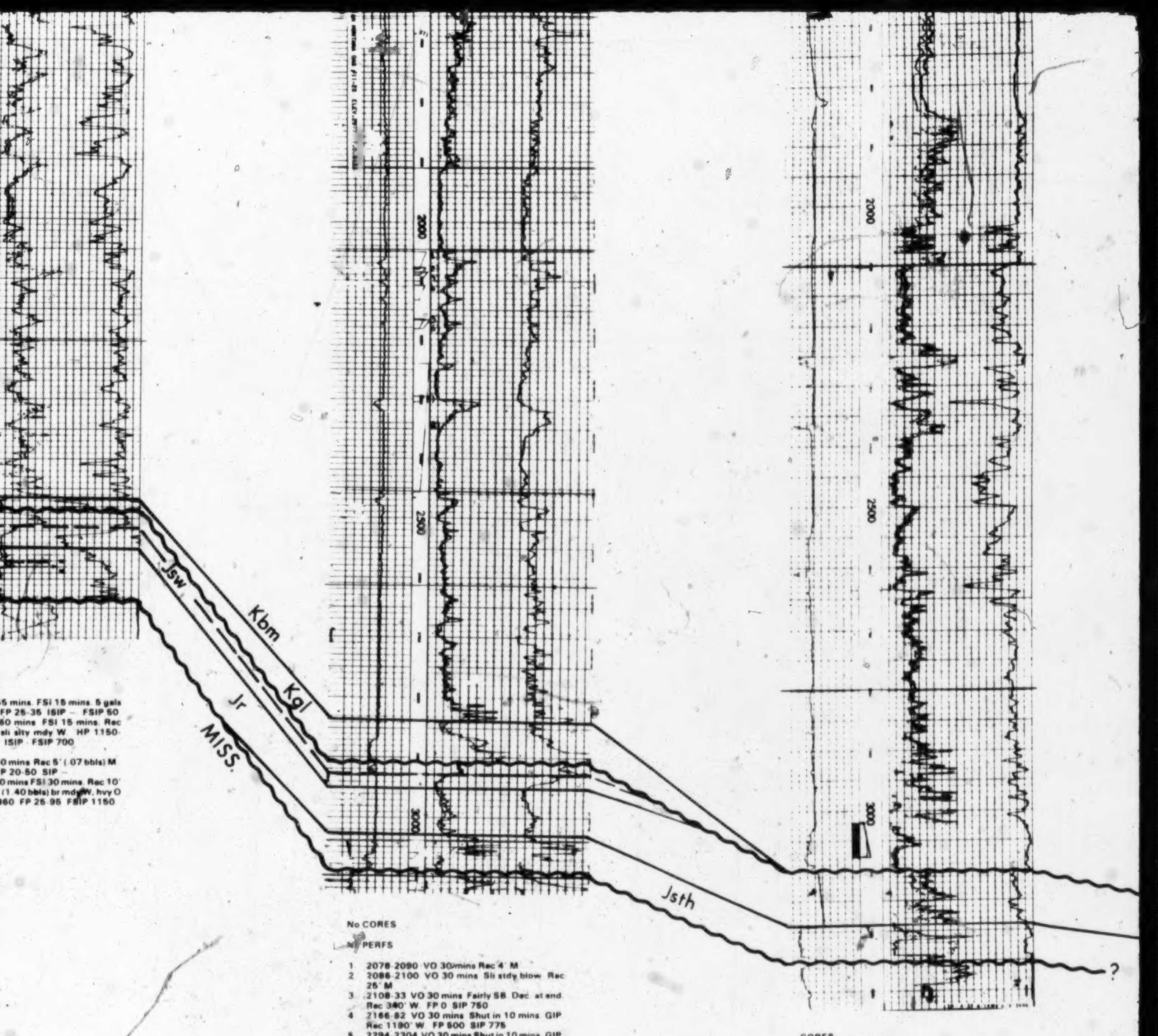
Wire Line Test
1 2470 VO 5 mins 17 sec. SI 3 mins 20 sec. Rec 20,000 c.c. fr W, 0.45 cu ft G. Res. 1.8 @ 60° 29% of mixture W. FP NR HP 1350 SIP 780

No CORES

No PERFS

1. 1695-1730 VO 45 mins. FSI 15 mins. 5 g
M. HP 940-925 FP 25-35 ISIP – FSIP 5
2. 1985-2026 VO 60 mins FSI 15 mins. R
360' (5.04 bbls) sli slty mdy W. HP 115
1120 FP 80-230 ISIP - FSIP 700
3. Misrun
4. 2585-2606 VO 40 mins Rec 5' (.07 bbls)
HP 1335-1335 FP 20-50 SIP –
5. 2786-2806 VO 90 mins FSI 30 mins. Rec 1
(.14 bbls) M, 100' (1.40 bbls) br mdy W, hvy
flkd. HP 1370-1360 FP 25-95 FSIP 115

11 of



5 mins. FSI 15 mins. 5 gals
FP 25-35 ISIP – FSIP 50
60 mins. FSI 15 mins. Rec
sli slty mdy W. HP 1150-
ISIP - FSIP 700

0 mins Rec 5' (.07 bbls) M
P 20-50 SIP –
0 mins FSI 30 mins. Rec 10'
(1.40 bbls) br mdy W, hvy O
960 FP 25-95 FSIP 1150

No CORES

No PERFS

1. 2078-2090 VO 30 mins Rec 4' M
2. 2086-2100 VO 30 mins. Sli stdy blow. Rec 25' M
3. 2108-33 VO 30 mins. Fairly SB. Dec. at end. Rec 340' W. FP 0 SIP 750
4. 2166-82 VO 30 mins. Shut in 10 mins. GIP Rec 1190' W. FP 500 SIP 775
5. 2294-2304 VO 30 mins Shut in 10 mins. GIP sli stdy blow. FP 0 SIP 875
6. 2240-2455 VO 30 mins. Shut in 10 mins. GIP & faint blow. Rec 5' M. FP 0 SIP 0
7. 3060-70 VO 45 mins. GIP VFB dying after 10 mins. Rec 2' M
8. 3085-95 VO 1 hr. Shut in 10 mins. GIP small blow, dec. sli Rec 265' sul. W. FP 0 SIP 1260
9. 3109-49 VO 30 mins. Shut in 15 mins GIP very stdy blow (non inflammable)
10. 2067-2085 Misrun
11. 2066-80 Misrun
12. 2050-80 VO 30 mins (no shut in). GIP & small stdy blow. Rec 430' sli GC & sli SW
13. 2108-2133 VO 30 mins Shut in 10 mins. Rec 340' W.
14. 2167-82 VO 30 mins. Rec 1160' SW

CORES
3020-3079 (58')

No PERFS

1. 3020-3079 VO 60 SI 60/30 Rec 15' M. HP 1483-1483 FP 43-43 SIP 1059-747
2. 3190-3210 VO 60 SI 60/60 Rec 2850' sli slty sul W. 100' M. HP 1641-1631 FP 485-1314 SIP 1430-1430
3. 3264-3300 VO 30 SI 60/60 WTS in 15 min., sul & slty. Rec 3300' slty sul gsy W. HP 1732-1729 FP 1159-1422 SIP 1436-1466

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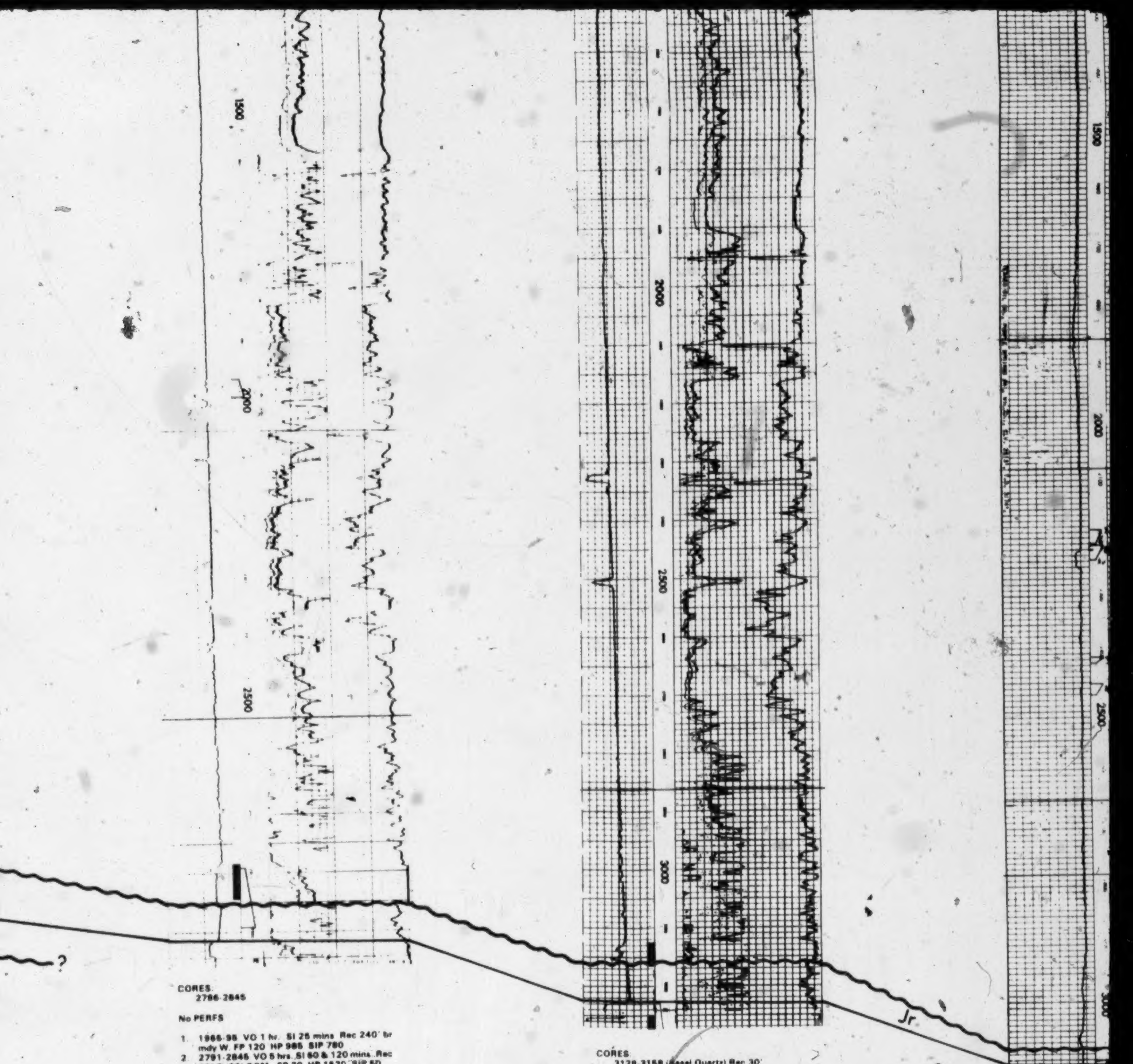

CORES:
2786-2845

No PERFS

1. 1966-96 VO 1 hr. SI 25 mins Rec 240' br mdy W. FP 120 HP 985 SIP 780
2. 2791-2846 VO 5 hrs. SI 60 & 120 mins. Rec 20' O. 30' OCM. FP 20 HP 1520 SIP 50

CORES
3128-3158 (Basal Quartz) Rec 30'
3250-3296 (Mississippian) Rec 46'

No PERFS

1. 3230-3296 (Jur/Miss) PF 5 VO 60 SI 10/30. SAB. FftS 8'', Rec 3230' sul SW. 12,400 ppm Cl. HP 1661-1625 FP 1386-1459 SIP 1496-1466

No CORES

No PERFS

1. 2186-2210
1080' or 15
2. VO 30 mins
bbls. M. 17
SIP 75
3. 2406-16 V
VSAB dying
& 2130' or
1100 FP 5
4. 2451-71 V
.84 bbls. M
1550 FP 3
5. 3101-3121
thru-out te
HP 1950 F
6. 3121-26 V
WAB. 110
5.17 bbls.
200
7. 3144-52 V
M

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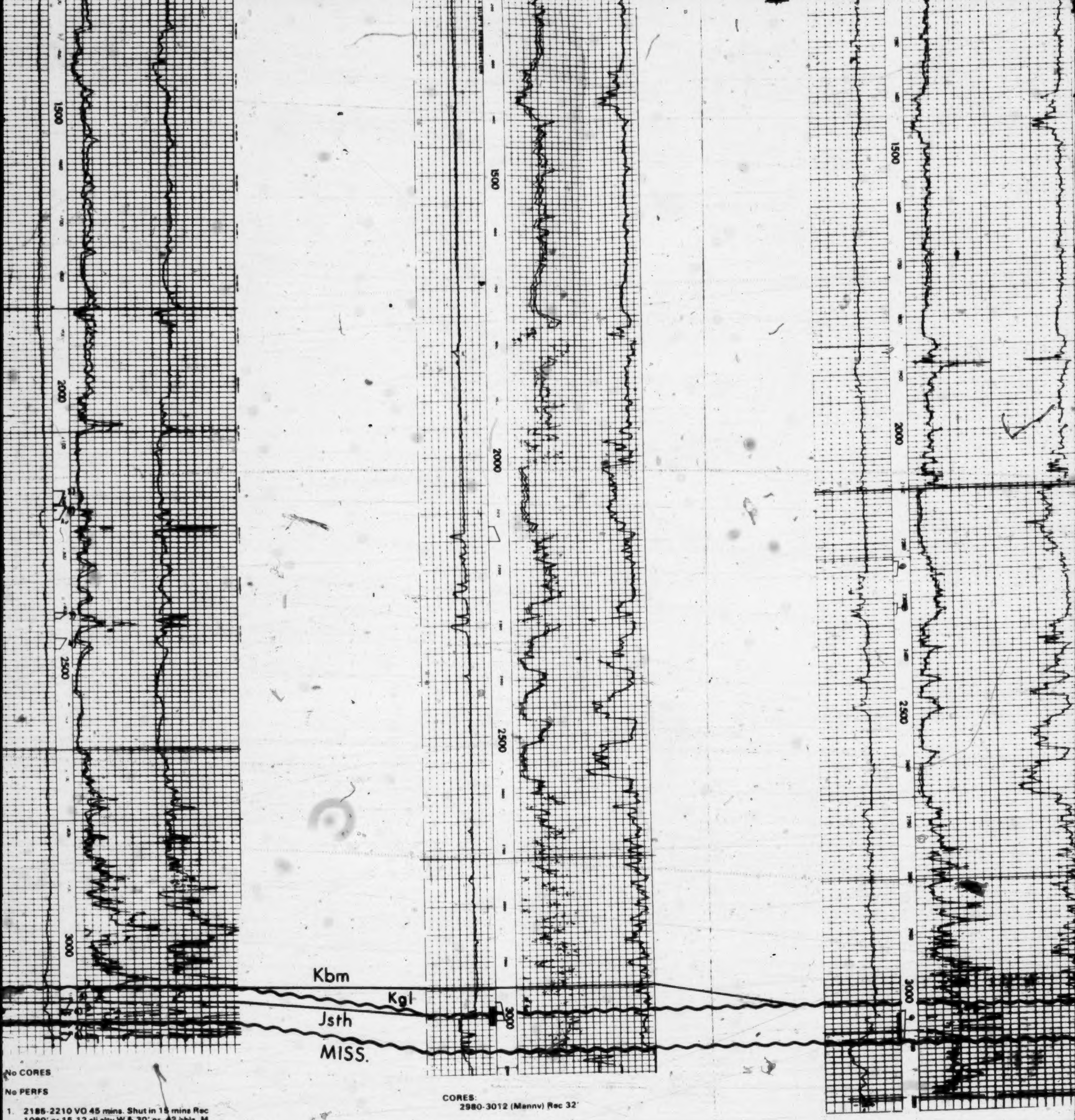


No CORES

No PERFS

1. 2186-2210 VO 45 mins. Shut in 15 mins Rec 1080' or 15.12 sli slty W & 30' or .42 bbls. M
2. VO 30 mins. Shut in 15 mins. Rec 60' or .84 bbls. M. 1770' or 24.78 bbls. SW. HP 1425 SIP 75 FP 475-875
3. 2405-15 VO 30 mins. Shut in 15 mins. GIP, VSAB dying in 10 mins. Rec 30' or .42 bbls M & 2130' or 29.82 bbls slty W. HP 1500 SIP 1100 FP 500-1000
4. 2461-71 VO 15 mins GIP, GAB. Rec 60' or .84 bbls. M 1350' or 18.90 bbls. SW. HP 1550 FP 300-700 SIP 925
5. 3101-3121 VO 1½ hr. GIP, WAB contin. thru-out test. Rec 65' or .91 bbls. hvly OCM. HP 1950 FP 0
6. 3121-26 VO 1½ hr. Shut in 15 mins. GIP, WAB. 110' or 1.54 bbls. sli OCM. 369' or 5.17 bbls. sul. SW. HP 1950 SIP 1525 FP 200
7. 3944-52 VO 30 mins. Rec 200' or 2.80 bbls M

CORES:
2980-3012 (Mannv) Rec 32'

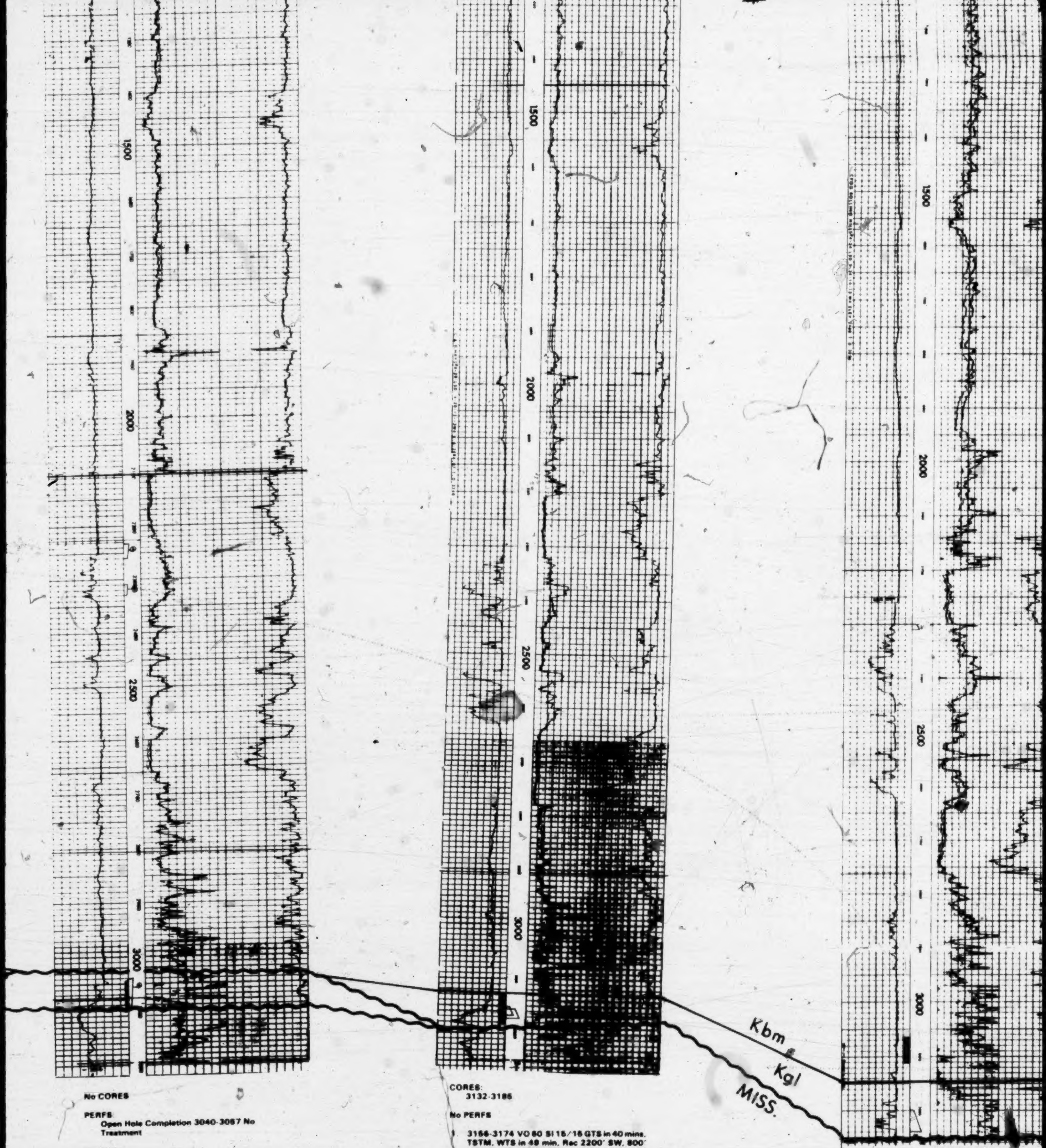
No PERFS

1. 2972-3004 (Mannv) VO 5/60 SI 60/90 SIP on PF, GB on VO, no GTS. Rec 500' O stained mdy W, 1900' O stained W. HP 1626-1626 FP 369-1069 SIP 1481-1430
2. 2125-2150 (Bow Is) VO 5/60 SI 60/60. SAB, GTS in 3 min. @ max. 34.5 Mcf/d 65 psi. ½'' ch. Rec 200' drlg M, 280' mdy W. HP 1174-1172 FP 230-295 SIP 897-847

No CORES

PERFS:
Open Hole Completion 3040-3057 No Treatment

No DST's



No CORES

PERFS
Open Hole Completion 3040-3067 No Treatment

No DST's

CORES:
3132-3185

No PERFS

1. 3166-3174 VO 60 SI 15/15 GTS in 40 mins, TSTM, WTS in 49 min, Rec 2200' SW, 800' OCSW HP 1806-1806 FP 650-1380 SIP 1560-1537
2. 3152-3169 VO 90 SI 15/20 GTS in 71 min, TSTM, Rec 775' O (6% BS&W) HP 1903 FP 140-247 SIP 1306-1350

CORES:
3168-3211 Rec 100%

No PERFS

1. 2300-10 VO 60 SI 30/30 mins GTS in 1½
196 mcfpd remaining stdy. Rec 70' GC d
M. HP 1280-1280 FP 20-40 SIP 925-93
2. 3200-50 VO 60 SI 30/30 mins Rec 980'
gey SW HP 1790-1766 FP 175-486 S
1446-1356

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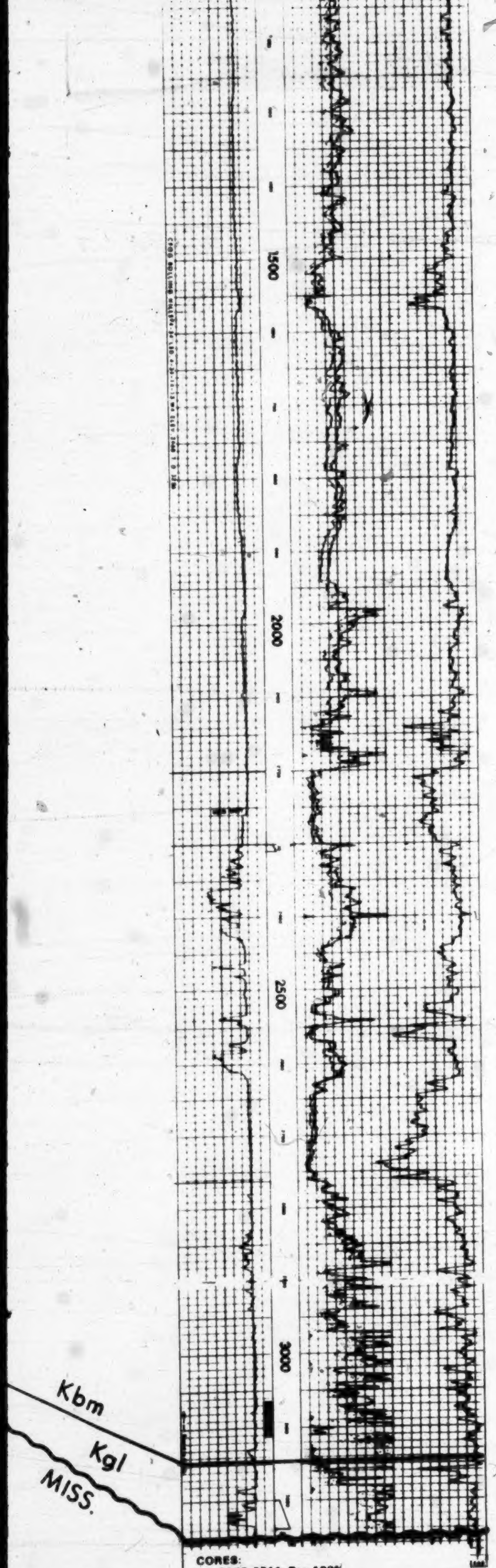
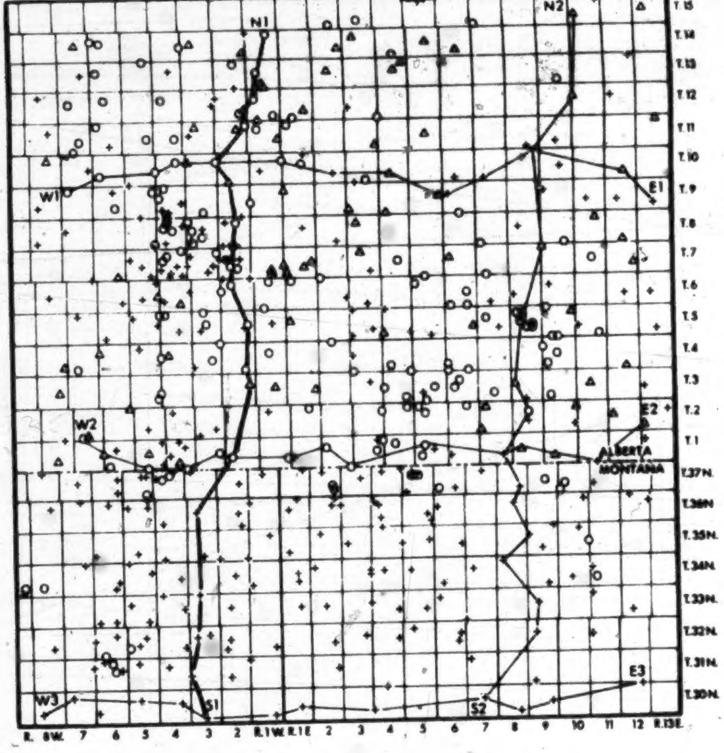


CORES:
3166-3211 Rec 100%

No PERFS

1. 2300-10 VO 60 SI 30/30 mins GTS in 1½ @ 186 mcfpd remaining stdy. Rec 70' GC drlg M. HP 1280-1280 FP 20-40 SIP 926-936
2. 3200-50 VO 60 SI 30/30 mins Rec 980' sli gsy SW HP 1790-1766 FP 176-486 SIP 1446-1366


N1
N2
W1
E1
W2
E2
ALBERTA
MONTANA
W3
S1
S2
E3
T.15
T.14
T.13
T.12
T.11
T.10
T.9
T.8
T.7
T.6
T.5
T.4
T.3
T.2
T.1
T.37N.
T.36N.
T.35N.
T.34N.
T.33N.
T.32N.
T.31N.
T.30N.
R. 8W. 7 6 5 4 3 2 R.1W. R.1E 2 3 4 5 6 7 8 9 10 11 12 R.13E.

CROSS SECTION LOCATION MAP
SOUTHEASTERN ALBERTA-NORTHERN MONTANA

0 5 10 15 20 25 30
MILES (Approx.)

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FIGURE 15

STRUCTURAL CROSS-SECTION

S1S-N1S

DATUM: 2200 feet above sea level.

B. Hayes
University of Alberta
1981

VERTICAL SCALE: 1" = 200'